Established by BENJAMIN SILLIMAN in 1818.

THE AMERICAN JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS GEO. L. GOODALE, JOHN TROWBRIDGE, H. P. BOWDITCH AND W. G. FARLOW, OF CAMBRIDGE,

PROFESSORS O. C. MARSH, A. E. VERRILL AND H. S. WILLIAMS, OF NEW HAVEN,

PROFESSOR GEORGE F. BARKER, OF PHILADELPHIA,
PROFESSOR H. A. ROWLAND, OF BALTIMORE,
MR. J. S. DILLER, OF WASHINGTON.

FOURTH SERIES.

VOL. VI—[WHOLE NUMBER, CLVI.]

No. 31.—JULY, 1898.

WITH PLATE I.

NEW HAVEN, CONNECTICUT.

1898.

TUTTLE, MOREHOUSE & TAYLOR, PRINTERS, 125 TEMPLE STREET.

Published monthly. Six dollars per year (postage prepaid). $6.40 to foreign subscribers of countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks.

CROCOITE.

A rare species from a new locality. Magnificent crystallizations which in color, lustre, perfection and beauty, are superior to the old Siberian examples. No low-priced specimens, but good ones are cheap at $5.00 to $8.00 each. We can send you one express paid, for inspection, with the certainty of your approval.

Send for descriptive "New Arrival List."

THE COMPLETE MINERAL CATALOGUE, 186 pages, 40 engravings. Contains tables giving names, composition and form of all known species and varieties, with an up-to-date supplement. A Metallic Classification of minerals according to elements contained. Index of names and other valuable lists. Prices postpaid, Paper bound, 25 cts.; Cloth, 50 cts.; Calf interleaved, $1.00.

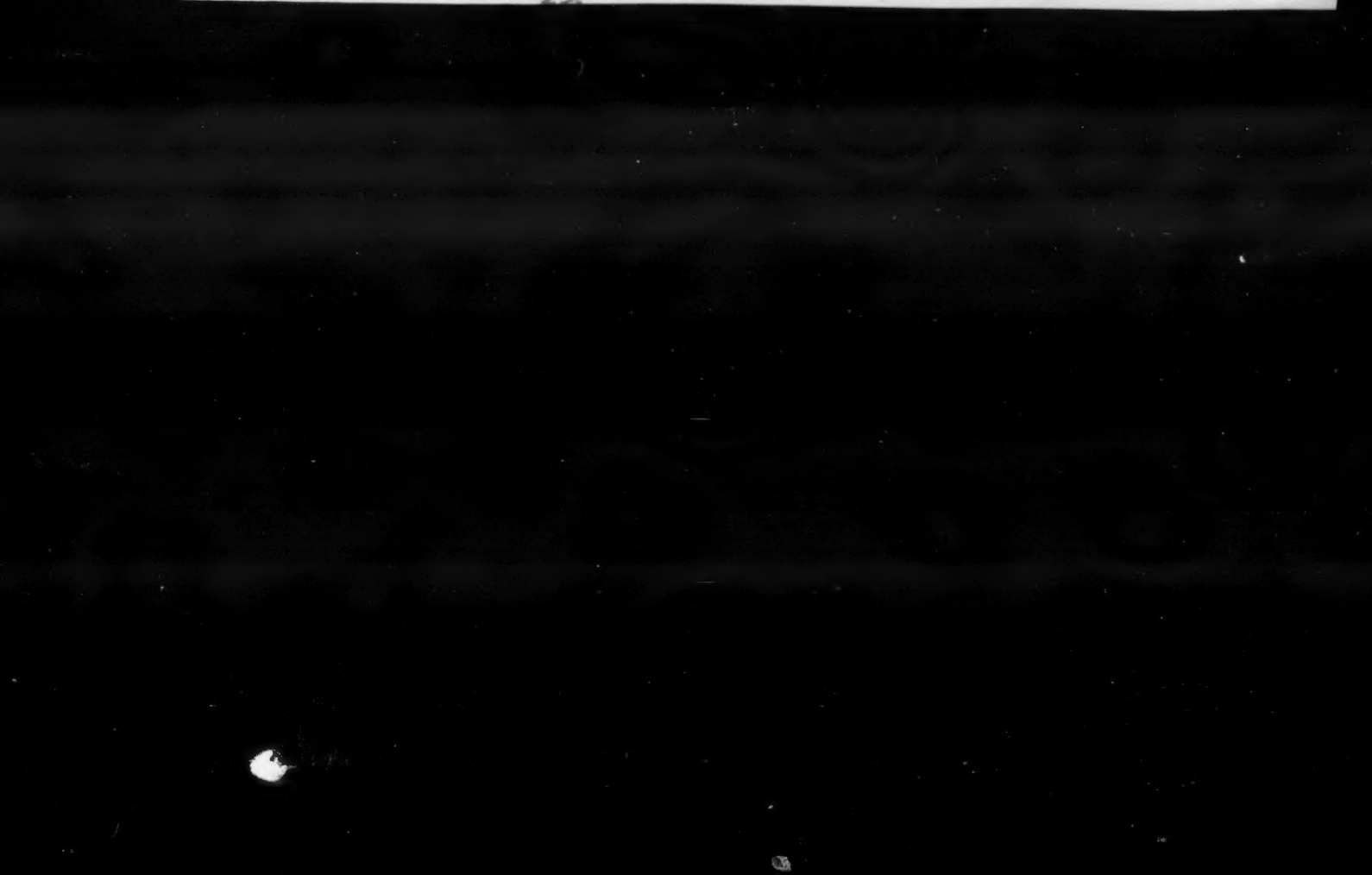
Minerals purchased in quantity. Rare and beautiful crystallizations especially wanted. Correspondence and samples solicited.

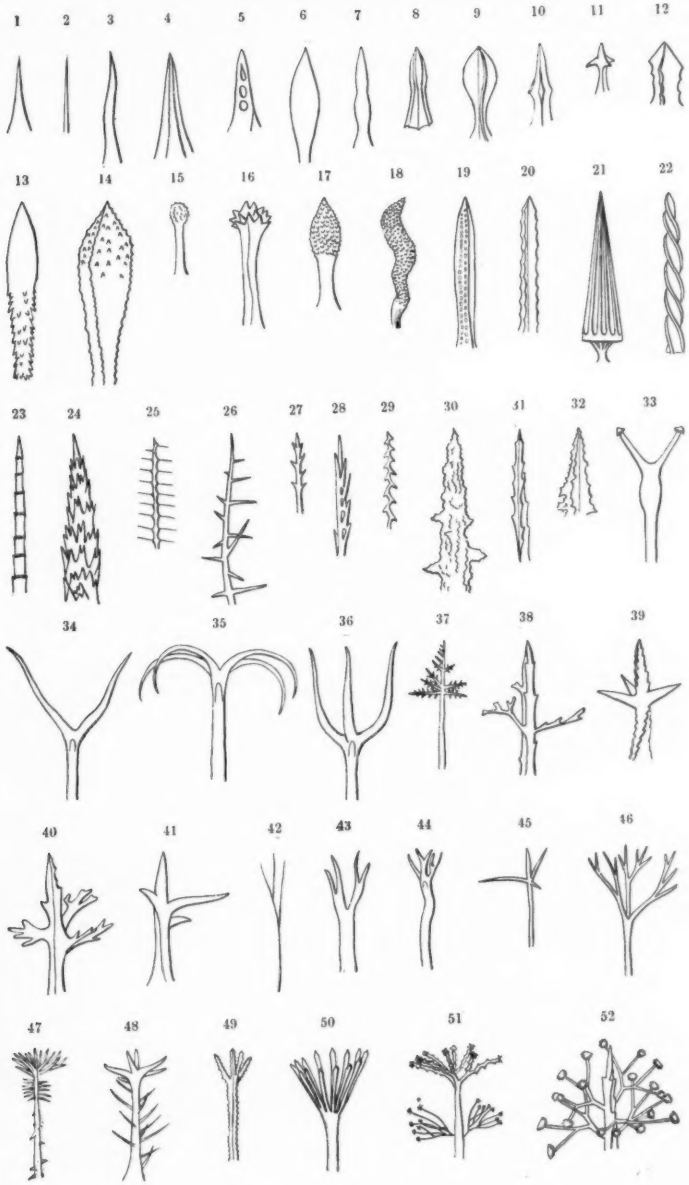
Dr. A. E. FOOTE,

WARREN M. FOOTE, Manager.

1317 Arch Street, Philadelphia, Pa., U. S. A.

Established 1876.





SPINES OF RADIOLARIA.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. I.—*The Origin and Significance of Spines: A Study in Evolution;* by CHARLES EMERSON BEECHER. (With Plate I.)

INTRODUCTION.

THE presence of spines in various plants and animals is, at times, most obvious to all mankind, and not unnaturally they have come to be regarded almost wholly in the light of defensive and offensive weapons. Their origin, too, is commonly explained as due to the influence of natural selection, resulting in the greater protection enjoyed by spiniferous organisms. But when, upon critical examination, it is seen that some animals are provided with spines which apparently interfere with the preservation of the individual, that other animals develop spines which cannot serve any purpose for protection or otherwise, and that spines themselves are often degenerate or suppressed organs, then it becomes evident that the spinose condition may have other interpretations than the single one of protection.

The object of this article is to make a few observations on spinosity, especially among invertebrate animals, and to endeavor to arrive at some general conclusions relating to the origin and significance of this condition. It is believed that the results have a broader application than is at first apparent, and underlie important laws and principles of organic evolution. In closely related species, the presence or absence of spines seems in itself a trivial character, indicating at best only specific differences, yet it will be shown that the spines are often the expression of important vital adjustments and conditions, and are not mercly external features of the same value

as color and many other skin or superficial characters. As will be indicated later on, spines may also arise through the operations of a number of forces and conditions, and it may well be asked, therefore,—Do spines have any profound significance? It must be granted at the outset that apart from other characteristics, or when regarded as simple spiniform extensions of certain tissues or organs, they have no such value or meaning. How, then, should they be considered? The reply is evident: Their importance lies not in what they *are*, but in what they *represent*. They *are* simply prickles, thorns, spines, or horns; they *represent*, as will be shown, a stage of evolution, a degree of differentiation in the organism, a ratio of its adaptability to the environment, a result of selective forces, and a measure of vital power.

After studying numerous organisms, the writer is led to believe that in every case no single reason is sufficient to account for this spinose condition. The original cause may not be operative through the entire subsequent phylogeny, so that spines arising from external stimuli and then serving important defensive purposes may at a later period practically lose this function; or spines may become more and more developed simply by increasing diversity of growth forces, or through the multiplicity of effects. In this way, causes may follow, overlap, or even coincide with each other; but in interpreting special cases, the problems involved may be quite complicated and often obscure.

In reviewing the development of animal life from the earliest Cambrian to the present, one cannot avoid being impressed by the groups of spinose forms which appear here and there throughout geologic time, and give a special phase to contemporary faunas. Tracing these one by one through their geological development, it is noticed that each group began its history in small, smooth, or unornamented species. As these developed, the spinose forms became more abundant until after the culmination of the group is reached, when this type either became extinct or was continued in smaller and less specialized forms. In applying this principle to any order of plants or animals, several precautions are necessary. The estimate must be based approximately upon the general average of the totality of specific characters, whether a genus, family, order, or even a class is being considered. A short-lived family or genus, or the terminal members of specialized groups, therefore, cannot be taken as representing the developmental status of the larger divisions, because they culminated and disappeared independently of the culmination of the class to which they belong. On a small scale, however, each epitomizes the rise and decline of the larger group, and the principles of

correlation commonly applied in ontogeny and phylogeny can likewise be used in the study of spines and spiniferous species, with equally exact results, whenever the principal factors are understood.

Law of Variation.

Before undertaking any general or special examination of the life histories and interpretation of spinose organisms, it is desirable to consider briefly some of the biogenetic principles which are considered to bear directly on the problems here under discussion.

First among these is the law of variation or change, which is so generally recognized as to require but the briefest restatement.

The organic as well as the inorganic world is subject to all the forces of nature, internal and external, molecular and molar, and even a partial stability is gained only through a regulated adjustment. In organisms, this change is momentary and persistent, while in most inorganic substances, it is slow and intermittent. The results of this continual readjustment constitute modification, which may be progressive or regressive, continuous or discontinuous (in the sense of accelerated, uniform, or retarded). They are everywhere present and the causes always operative. Throughout life, the individual changes, and in addition varies from all other individuals. The family, also, changes with time, and likewise differs from other families. Variation is everywhere present. Moreover, it is generally accepted, and is so taken here, that, in its results, this variation is not haphazard, but is normally in accordance with certain demands or in harmony with certain surroundings. Whether an organism itself tends to vary in all directions, or is chiefly subject to modifications from external forces, does not alter the preceding statement.

Cope[11] has considered variation as either physico-chemical (molecular) or mechanical (molar). The influence of the first is known as physiogenesis and of the second as kinetogenesis. In the animal kingdom, the potency of kinetogenesis is greater as an efficient cause of evolution; while in the vegetable kingdom, physiogenesis is apparently of more importance.

The tendency of variation is always in the direction of the establishment of an equilibrium between the organism and its environment. However, the laws of the development of the earth preclude the possibility of a constant environment, and therefore a perfect, permanent, and uniform equilibrium between life and surroundings is unattainable.

The manner of variation is clearly defined as *progressive* and *regressive*. Progressive variation is one of the essential

factors of evolution, while regressive variation is towards dissolution. Since the main history of life is told through processes of the former, progressive variation is far greater in importance; while, in general, regressive variation can be applied only to late periods in the history of groups or forms now in their decadence, or to others which in past times have suffered decline and extinction.

The summary of the operation of the law of multiplication of effects, as given by Herbert Spencer[66], may well be stated here, as it emphasizes one of the principles through which spines have originated.

"It manifestly follows that a uniform force, falling on a uniform aggregate, must undergo dispersion; that falling on an aggregate made up of unlike parts, it must undergo dispersion from each part, as well as qualitative differentiations; that in proportion as the parts are unlike, these qualitative differentiations must be marked; that in proportion to the number of the parts, they must be numerous; that the secondary forces so produced must undergo further transformations while working equivalent transformations in the parts that change them; and similarly with the forces they generate. Thus the conclusions that a part-cause of evolution is the multiplication of effects, and that this increases in geometrical progression as the heterogeneity becomes greater, are not only to be established inductively, but are deducible from the deepest of all truths."

Modification, therefore, may properly include the results of the multiplication of effects. Furthermore, from a knowledge of the life history of the organic world, it is known that this change has been progressive, resulting in the evolution of the higher from the lower, of the complex from the simple, and of the definite from the indefinite.

It must now be asked,—Is the amount of variation without limit or is it restricted within bounds which can be determined? As far as can be seen, the limitations of the forms of species of animals and plants end only with the aggregate number of possibilities within the functional scope of the organism. Beyond, in either direction, is death, and a passage from the organic into the inorganic. The restrictions of variation are chiefly those of temperature, pressure, motion, light, space, time, and matter. Within certain limits, these clearly bound the horizon of known possible life. Further, the material constitution of the organic world is naturally subject to ordinary mechanical and chemical laws.

If, instead of the preceding, general, and therefore rather abstract statements of the limits of variation, the subject is

considered from the concrete, objective side, the limits between which are found all the variations actually presented by any character or set of characters, in the animal or the vegetable kingdoms, can at once be determined. The fact that the organic world can be divided into kingdoms, sub-kingdoms, classes, orders, etc., and definitions of the divisions given, in itself furnishes sufficient evidence that these have been the limits of organic change, at least under present terrestrial conditions. This does not imply that the phylogenies of groups of animals and plants do not converge and coalesce, and join larger and larger phyla in past ages, so that the gaps between unlike forms are gradually filled by complete series. It does, however, express the definite heterogeneity of the results of development.

For the sake of illustrating an extreme range of variation, it will be granted that the assemblage of characters by which a mammal is now recognized precludes mammalian variation into a cold-blooded, non-vertebrate, lungless animal. Likewise, the mammalian skeleton cannot be siliceous or chitinous. Externally, mammals may be smooth, hairy, scaly, or plated, but not feathered. There may be found numerous gradations from the smooth to the plated state, and a great range of variation in each type of epidermal structure. In vertebrate animals generally, the hair may vary in length, in fineness, in color and shape; it may form bristles, or spines, or feathers; and as a skin character, it is related to horn-sheaths, hoofs, nails, claws, scales, and teeth. These constitute the limits of modification in epidermal or exoskeletal growths. The types are few, but the variety in each is almost infinite. The variation may be seen in individuals, but becomes greater in species, and increases still more in larger groups. The gradations are numerous between the hair of a Beaver and the spines of a Porcupine; between the horns of the Giraffe, Rhinoceros, and Antelope; between the nails of Man and the claws of the Carnivora; and between the teeth of a Dog-fish and those of a Tiger.

Definition of Terms.

In the beginning, it is well to understand the meaning and extent of the terms included under the comprehensive word spine. In a general sense, *spine* is here used to cover any stiff, sharp-pointed process. A *prickle* is restricted in use to the small, sharp-pointed, conical projections which are purely cuticular; as in the Rose and Blackberry. A *thorn* is a sharp process on plants, usually representing a branch or stem. A *horn* is an excrescence on the head of certain animals, and is properly hollow. An *antler* is a solid bony process, usually

deciduous, and generally confined to the male; as in the Deer or Elk. A *spur* is a term applied to the claw-like process on the legs and wings of some birds, and on the hind legs of *Ornithorhynchus* and *Echidna*.

The word spine, therefore, is most comprehensive, and is here intended to include the modified hairs of the *Echidna* and Porcupine; the sharp, prickly scales of the Horned Toad (*Phrynosoma*); the pointed spiniform projections on the shells of Mollusca; the spinous prominences on the test of Crustacea and insects; the fin spines as well as those on the opercula and scales of fishes; the generally movable processes of Echinoderms; the projecting rays and processes of Radiolaria, etc., etc. The vertebral column and also the processes from the separate vertebræ are known as spines, but as these are distinctly internal structures, they will not be considered in this connection.

In nearly all classes of organisms, spines have been developed independently, and simply represent cases of parallel development of similar structures or morphological equivalents. They possess analogy of form without necessary homology of structure, and accordingly have no common phylogenetic connection. Therefore, if the relationships between the smooth and spinose forms belonging to any group of animals or plants can be traced, and the simplest and most primitive condition in each case, as well as the highest stage of progressive development, can be ascertained, their relative significance from an evolutionary standpoint may be confidently determined.

Growth of a Spine.

The growth of a spine is either direct and progressive, or indirect and regressive. It is direct when it is developed by the addition of new tissue. In this way, growth is attained in the antlers of a Deer, the horns of a Cow, the ordinary spines of Brachiopods, Mollusca, and Crustacea, and in other similar examples covering the majority of cases. Growth is indirect, however, when the spine represents atrophy or suppression of an organ through the loss of its accessory parts, as in the thorns of the Locust and the Barberry, the spiniform termination of the stems of the Pear, or the spurs on the Python.

The direct development of a spine is essentially the same process in all cases. At a given point on the surface of an organism, there first appears a slight elevation, which becomes higher and higher, and is usually conical in form. This cone represents the simplest type of spine; and among animals and plants, most spines conform to this primitive pattern (figures 1–5).

Often there are various kinds of surface ornaments, which by growth and differentiation develop into spines. By rhythmic, alternating areas of accelerated or retarded growth, the

FIGURES 1–5.—Different stages in the growth of a spine. 1, plane surface; 2, slight elevation; 3, node; 4, short spine; 5, completed simple spine.

concentric laminæ on many molluscs may produce spines, as shown in figure 26. In the same way, the radiating ridges may be diversified into a row of spines, as represented in figure 6. Further, the surface may be reticulate, with longitudinal and transverse lines, and at the points of intersection, nodes and often spines are formed after the manner shown in figures 7–12. The longitudinal or vertical lines may become obsolete, leaving the spines to be borne on the transverse or horizontal lines (figure 10). In other cases, the horizontal lines disappear, leaving the spines on the vertical lines (figure 11). Finally, both horizontal and vertical lines become obsolete, and then only the spines remain, as shown in figure 12.

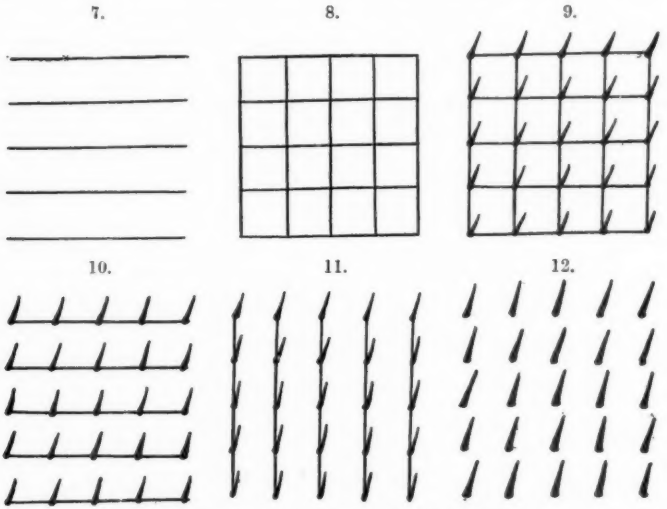
6.

FIG. 6.—A profile of a single radiating ridge of *Spondylus princeps*, showing the series of flattened spines.

The indirect production of spines is not always evident, for if the ontogeny or phylogeny of the individual is unknown, its direct or indirect development cannot be determined. An excellent example of indirect, or regressive, growth of spines is afforded in the common Barberry (*Berberis vulgaris*), on the summer shoots of which are shown most of the gradations "between the ordinary leaves, with sharp bristly teeth, and leaves which are reduced to a branching spine or thorn. The fact that the spines of the Barberry produce a leaf-bud in their axil also proves them to be leaves"[24] (figure 13).

It should be noted that the process of spine development illustrated in *Spondylus* (figure 14) is directly opposed to that of the Barberry. In the former, the initial growth is smooth, then faint concentric and radiating lines appear, which gradually grow stronger, developing more or less regular inequalities; and by the excessive growth of these variations, spines are formed. In the Barberry, there are at

first normal leaves, which are followed by others more and more toothed and bristly, until the leaf is represented by a branching spine, while finally spines only are formed. The *Spondylus* represents a progressive increase in growth to produce the spines, while the Barberry exhibits a progressive



FIGURES 7–12.—Diagrams showing growth and differentiation of ornament into spines. 7, surface with parallel lines; 8, surface with regular reticulate lines; 9, same, with spines developed at the points of intersection; 10, same, with the vertical lines obsolete, but still represented by the vertical rows of spines; 11, same, with the horizontal lines obsolete, but still represented by the horizontal arrangement of the spines; 12, same, with all lines obsolete, but both series represented by the vertical and horizontal arrangement of the spines.

decrease of growth, or an "ebbing vitality," as it has been termed by Geddes.[20]

The spines are the final results of both the direct and indirect modes of production; the direct, through a process of building on new tissue, and the indirect, through a process of dwindling away to all but the axial elements. These differences are graphically expressed in figures 13 and 14.

Attention should be called to the four kinds of spine production in different organisms. (1) In the Radiolaria, Echinoids, the Giraffe, Cattle, and the Rhinoceros, the spines or horns are persistent, and grow by additions to the original structure. The new tissue may be superficial, subterficial, interstitial, or formed by synchronous resorption and growth. (2) In the Crustacea and Articulata generally, and in the Deer,

Elk, etc., the spines are moulted, or shed, periodically. In their various stages, these types (1 and 2) can be studied only by means of separate specimens consecutive in age, or by observing the metamorphoses in one individual. (3) In the shells of Brachiopods and Mollusca, the stages of growth of the individual are generally retained throughout life, and the

13. 14.

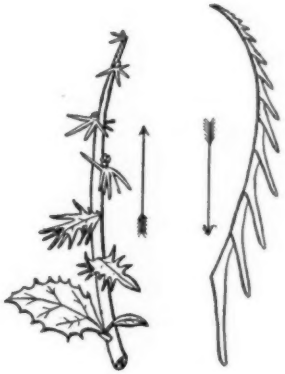


FIGURE 13.—Summer shoot of Barberry, showing the gradations between leaves and spines. The arrow indicates the direction of growth. (After Gray.)

FIGURE 14.—Profile of one of the primary rays of *Spondylus imperialis*, showing the series of spines. The arrow indicates the direction of growth.

15. 16.

17 18

FIGURE 15.—Example of spine growth by simple increscence. Horn (left) and horn-core (right) of Ox. (After Owen.)

FIGURE 16.—Stages of spine growth by successive replacement. Antler series of Red Deer, at ages of 1, 2, 3, etc., years. (After Owen.)

FIGURE 17.—Stages of spine growth by serial repetition. Profile of a series of spines on one of the primary radii of *Spondylus imperialis*.

FIGURE 18.—Stages of spine growth by decrescence. Transformation of leaves into spines in *Berberis vulgaris*. (After Gray.)

successive development of spines may be studied, therefore, in a single example. (4) Spines produced by suppression, as in the Barberry, express their origin through a series of gradations between separate parts; while in others, suppression is brought about by the loss of structures.

The first type mentioned develops horns or spines by simple increscence (figure 15); for example, the Ox: the second, by successive replacement (figure 16); as in the Deer: the third, by serial repetition (figure 17); for example, *Spondylus:* the fourth, by decrescence (figure 18); for example, the Barberry.

Localized stages of growth.—By the multiplication of surface ornaments through the process of interpolation, many Mollusca present stages of spine development in two directions. (1) The normal series is represented by the succession of spines along a

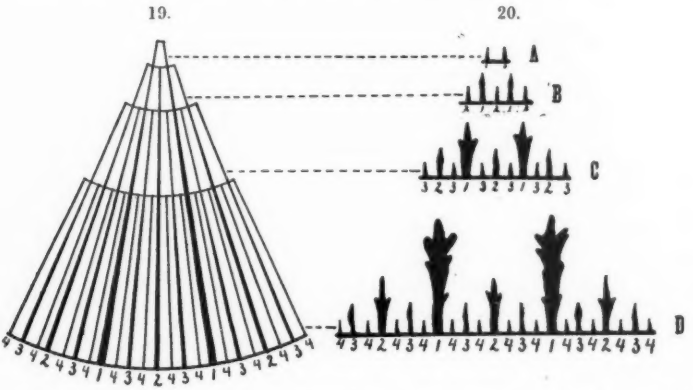


FIGURE 19.—Sector showing in diagram the multiplication of radiating lines by interpolation. The two primary radii (1, 1) are the only ones continuing through the whole four zones. The first zone has 2 radii; the second, 5; the third, 11; and the fourth, 23.

FIGURE 20.—Profiles of the spines produced on the various radii at the four zones, as indicated in the preceding figure. A, the spines on the two primary radii of the first zone; B, the spines on the second zone, showing the growth of those on the two primary radii (1, 1), and the small spines on the newly interpolated radii (2, 2, etc); C, the spines on the radii in the third zone; D, the spines at the bottom of the fourth zone. The two large compound spines are on the two primary radii. Their development may be traced by following them through A, B, C, to D. The next three longest spines (2, 2, 2) are tricuspid, and represent the stage of spine development attained by the spines on the radii which were interpolated on the second zone. The next six smaller spines (3, 3, 3, etc.) are on radii which were introduced on the third zone. The twelve small spines (4, 4, 4, etc.) are on the radii introduced on the fourth zone. Thus there are four stages of spine growth shown on the lower margin of the fourth zone, and these correspond to the four stages exhibited by the series of spines on one of the primary radii running through the four zones.

single sector of growth. For instance, in the radial plications of a *Spondylus* or *Lima*, the earliest and primitive spines are found near the beak, while those on the ventral border of an adult specimen are the latest and most highly developed (figure 30). These successive stages, therefore, are in the direction of growth, and may be called longitudinal. (2) By the radial divergence of the ribs or plications and the interpolation of additional ones at various intervals, as many transverse compound series of spines finally appear along the periphery as there are primary radii. Hence, in a given case, there may be two radii continuing to the beak, then by interpolation there are successively 5, 11, 23, etc., radii, the highest number being found at the periphery (figures 19, 20). Moreover, by taking the distal spines on these 23 rows, there result the same stages of spine development as shown in the longitudinal series along any primitive plication (figure 20). A Pelecypod shell like *Spondylus* is here used to illustrate this process, but the application may also be made to the Brachiopods as well as to the conical non-coiled Gastropods. In a coiled form like a Cephalopod or an ordinary Gastropod, the longitudinal lines would follow the whorls spirally, and the transverse lines would correspond to the lines or increments of growth of the shell. Species in which the radii are all introduced at an early stage of growth (many species of *Cardium*, *Pecten*, *Lima*) or in which the radii multiply by regular dichotomy would show, of course, only the longitudinal series, for at the margin of the shell, the radii would be of the same size and age, and the spines uniform.

The foregoing example illustrates an important principle of ontogeny; namely, that in organisms which repeat various parts during their growth, these parts will develop or pass through a series of stages corresponding to the initial and subsequent stages of the parts repeated. In this way, structures appearing late in the ontogeny of the individual will present primitive infantile and adolescent characters. Further development, if such takes place, will pass through a progressive series of ontogenetic changes, and if the stages of growth are by serial repetition and thus are retained in the part, it will be found that such stages can be correlated with those appearing early in the life or history of the individual. Therefore, in studies of this kind, it is possible to take a structure appearing at maturity, and from it deduce or predicate as to what were some of the early characteristics of the whole individual. This principle is termed localized stages of growth by Jackson[37], and was first noticed by him in some investigations on Echinoderms.

Compound Spines.

A simple, sharp, conical process expresses only the primitive type of spine. In plants and animals, it is the most common form found, and is the first stage of spine differentiation. From this type, the myriad forms of spines known in the organic world are produced by almost insensible gradations. It is needless to attempt a detailed description of this infinite variety; but, as a single illustration, some of the leading forms of spine differentiation among the Radiolaria are here shown (Plate I). These figures are taken from Haeckel's "Report

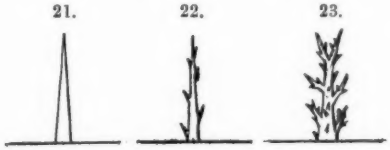


FIGURE 21.—Simple spine.
FIGURE 22.—Spine, with lateral spinules.
FIGURE 23.—Spine, with forked apex and lateral spinulose spinules.

on the Radiolaria,"[26] and generally represent enlargements of from 100 to 400 diameters.* Probably no other class of

* EXPLANATION OF PLATE I.

Spiniform processes of recent Radiolaria taken from the shells of the following species:

Fig. 1.—Heliosphæra coronata.
Fig. 2.—Astrosphæra stellata.
Fig. 3.—Astrophacus solaris.
Fig. 4.—Stylosphæra calliope.
Fig. 5.—Heliodiscus glyphodon.
Fig. 6.—Pripodictya triacantha.
Fig. 7.—Pleuraspis horrida.
Fig. 8.—Hexacontium sceptrum
Fig. 9.—Acanthosphæra clavata.
Fig. 10.—Acanthosphæra clavata.
Fig. 11.—Cromyodrymus quadricuspis.
Fig. 12.—Hexacontium clavigerum.
Fig. 13.—Orosphæra horrida.
Fig. 14.—Staurocyclia phacostaurus.
Fig. 15.—Tripospyris capitata.
Fig. 16.—Archipera cortiniscus.
Fig. 17.—Tripospyris conifera.
Fig. 18.—Orosphæra serpentina.
Fig. 19.—Staurolonche pertusa.
Fig. 20.—Astrosphæra stellata.
Fig. 21.—Staurodictya elegans.
Fig. 22.—Hexastylus contortus.
Fig. 23.—Stephanospyris excellens.
Fig. 24.—Podocyrtis magnifica.
Fig. 25.—Hexancistra mirabilis.
Fig. 26.—Dictyophimus Cienkowskii.
Fig. 27.—Elatomma juniperinum.
Fig. 28.—Castanura tizardi.
Fig. 29.—Pleuraspis horrida.
Fig. 30.—Staurocarynum arborescens.
Fig. 31.—Rhizosphæra serrata.
Fig. 32.—Phænocalpis petalospyris.
Fig. 33.—Aulospathis bifurca.
Fig. 34.—Aulographis bovicornis.
Fig. 35.—Aulographis ancorata.
Fig. 36.—Aulographis bovicornis.
Fig. 37.—Sphærozoum verticillatum.
Fig. 38.—Cladococcus pinetum.
Fig. 39.—Hexancistra triserrata.
Fig. 40.—Cladococcus stalactites.
Fig. 41.—Hexancistra quadricuspis.
Fig. 42.—Heliodrymus ramosus.
Fig. 43.—Heliodrymus dendrocyclus.
Fig. 44.—Aulographis pandora.
Fig. 45.—Cladoscenium ancoratum.
Fig. 46.—Cladococcus scoparius.
Fig. 47.—Auloscena penicillus.
Fig. 48.—Circostephanus coronarius.
Fig. 49.—Lychnosphæra regina.
Fig. 50.—Auloscena spectabilis.
Fig. 51.—Cœlospathis ancorata.
Fig. 52.—Octodendron spathillatum.

organisms presents greater variety, and many of the forms are repeated again and again, not only in various species of this group, but elsewhere both in the animal and vegetable kingdoms.

Whenever the development of a compound spine can be studied, it shows a gradual progress from the simple to the complex (figures 21–23). The antlers of the Red Deer (*Cervus elaphus*) furnish a familiar example. Fawns of the first year have antlers with only a single prong, a short front tine being added the second year; then "year by year as they are renewed they acquire a greater and still greater number of tines and branches, till they finally attain the complete stage, when their owner is termed a 'royal hart'"" (figure 16). Although somewhat conventionalized, the primary series of spines on the *Spondylus* shown in figure 20 exhibits the passage from simple to compound forms. An inspection of many species of *Murex* will show the stages in series presenting a greater complexity.

After spine development has reached its maximum growth and differentiation, evidence of old age may be exhibited in two ways: (*a*) The spines may be reduced by resorption, decay, or abrasion, and finally become obsolescent; or what is of greater import (*b*), they may gradually cease to be developed, as is especially shown in organisms in which spine growth is by serial repetition. Thus, in *Spondylus calcifer*, a young individual measuring about two inches across has marginal spines fully an inch in length. Even longer spines are found when the shell reaches a width of four inches. On attaining a maximum diameter of about six inches, spine growth gradually ceases, and the margin of the valves is entire and nearly smooth. At this stage, shell secretion is confined to excessive thickening of the valves. These senile stages of spine growth will receive further consideration under the discussion of ontogeny and phylogeny of spinous species.

Application of law of morphogenesis.—The manner in which spines arise from plane surfaces, or from the growth or modification of superficial structures, and also through the decadence of organs, has now been noticed. The spine may thus be taken as a unit for comparison, and its various stages of growth, which were shown to have a definite sequence, may be used in correlation to determine relatively the degree of spine specialization attained by any organism. Furthermore, enough data have been already given to lead to the suspicion that spines may represent the limits of ornamental or superficial differentiation or variation. At this point in the discussion, this statement must be considered as more suggestive than

conclusive. The proof of its reality will be more clearly shown later on.

Ontogeny of a Spinose Individual.

With few exceptions, the embryonic and larval stages of all organisms are devoid of specialized surface features. In other words, they are without ornament and without weapons. The exceptions to this rule seem to be readily explained under the principles of larval adaptations and accelerated development. Cases of the latter kind, therefore, can hardly be considered as exceptions, since they represent, not real larval features, but former adult characters which have been pushed back or which develop earlier so as to appear eventually in the larval or later embryonic stages. In the very earliest stages of embryonic development, the truth of the first statement becomes obvious, and accordingly the protembryonic, mesembryonic, metembryonic, neoembryonic, and typembryonic stages are without surface ornaments or spines.

Among Mollusca, the protoconch, periconch, and prodissoconch, or the early larval shells, are smooth and without ornament. Even the prodissoconch of very highly spinose species, as in *Spondylus*, is as smooth as that of the plainest species of *Ostrea*, *Anomia*, *Avicula*, etc. Likewise, the protoconch of the most specialized or most retrograde Cephalopod is perfectly plain. In the nepionic stages, the spiny *Murex* is without spines. In the Brachiopoda, the protegulum, or early larval shell, is always without sculpture; while the nauplius of Crustacea and the protaspis of Trilobites are generally spineless. The young of horned vertebrates are almost universally hornless, the Giraffe being the only mammal born with horns. The very young seedlings of plants are likewise spineless. In insects, the embryonic stages generally have simple cuticles, but in the larval stages of this class and the Crustacea, a great variety of spines and ornamental characters is developed. Altogether, it may be asserted that spines do not appear during the embryonic stages of animals and plants, and that their initial development is commonly post-larval.

Examples illustrating the ontogeny of a spinose form could be multiplied indefinitely, and taken from nearly every class of organisms. In all cases, practically the same sequence of events relating to the development of spines would be found. The organism would first be smooth, without sculpture or ornament, like the young of other organisms. At some stage of the ontogeny, the beginnings of spines would appear, and develop first into simple, and later, according to the stage of differentiation attained, into compound spines. This progression would finally reach the maximum, spine growth would

cease, and the surface of the organism would inversely revert to an early and more primitive type without spines. Normally, these changes would represent the infantile, adolescent, mature, and early and late senile periods of the life of the organism. In some cases, however, the stages of spine growth, or acanthogeny, do not agree with the ontogeny of the entire individual in respect to time, and here acceleration and the phylogeny of the species will be found to offer the proper explanation of the divergence.

As simple examples of the ontogeny of spiniferous species, the Mollusca afford especial advantages, owing to the fact already noticed, that the stages of development are commonly preserved in a single individual. In figure 24, the larval shell, or prodissoconch, of Pelecypods, or bivalve shells, is represented, and shows the usual type throughout a large portion of the class. The succeeding shell growth of the dissoconch is at first generally smooth, save for the fine concentric lines of growth (figure 25). In ornamented or spinose species, however, irregularities in the growth lines soon appear (figures 26, 27), and these shortly assume the characteristic surface sculpture of the normal adult. Thus, the prodissoconch of *Avicula sterna* is represented at *p*, figure 25, and is followed by regular concentric growth during the nepionic stages. In figure 26,

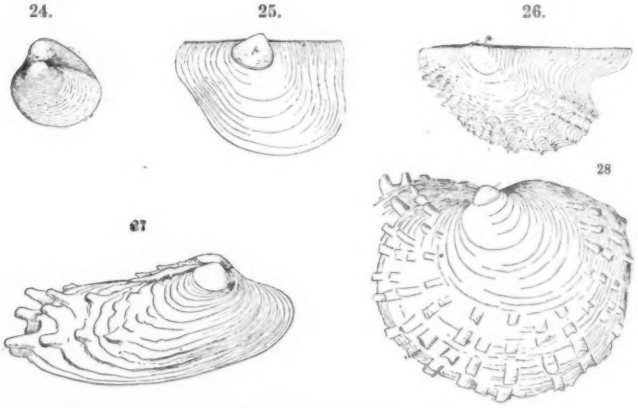


FIGURE 24.—Prodissoconch of *Ostrea virginiana*. ×43.
FIGURE 25.—Each stage of *Avicula sterna*; *p*, prodissoconch. ×19.
FIGURE 26.—Young *Avicula sterna*, showing the beginning of spine growth. ×3.
FIGURE 27.—Young *Saxicava arctica*. ×19.
FIGURE 28.—Young *Anomia aculeata*; *p*, prodissoconch succeeded by early smooth and later spinous dissoconch growth. ×30. (24–28 after Jackson.)

the spiny characters of early adolescence are added to the previous stages, and in later stages, the spines become more and more emphatic.

In *Spondylus*, the prodissoconch is the same simple form, and is succeeded by a nearly smooth Pecten-like stage, during which the animal was free (figure 29). After fixation, the growth is very irregular and ostræiform for a time, until the shell rises above the object of support, when all the most characteristic features of surface ornamentation become fully developed (figure 30). As the shells approach maximum growth, the spines gradually become shorter, and in old age, none are developed, even those of early growth being removed by the action of boring animals and by solution (figure 31).

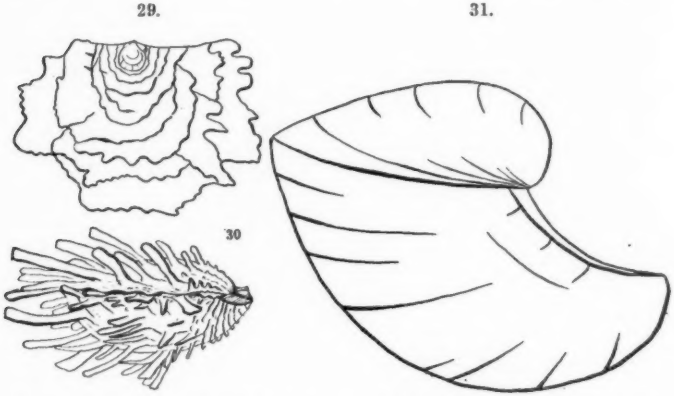


FIGURE 29.—Young *Spondylus princeps*. Right valve, showing pecteniform stage succeeded by ostræiform growth. Taken from apex of adult specimen; presented by R. T. Jackson. ×3.

FIGURE 30.—Side view of *Spondylus calcifer*, about one-third grown, showing the characteristic spinous growth. ½.

FIGURE 31.—Side view of *Spondylus calcifer*, showing the greatly thickened right valve and the entire absence of spines over the whole shell. ½.

It seems unnecessary to increase the number of examples showing the ontogeny of spinose individuals. The Deer and the Ox may be again cited in this connection. Both are born without horns, but during adolescence, the antlers of the Deer become longer and more complicated with each renewal, while the horns of the Ox are longer and more twisted. In old age, when the Deer has passed his prime, the antlers are more obtuse, and exhibit a tendency toward decline and obliteration. Suppression of the antlers is accomplished by the removal of the cause of antler growth and specialization, so that the

unsexing of the male results in small antlers, which are seldom branched, and become thickened by irregular deposits of bone (Owen[53]). Spines grow during the adolescence of the Horse-Shoe Crab, *Limulus polyphemus*, yet in old age they are obsolescent, being represented by rounded nodes.

As examples illustrating the accelerated development of spines in widely separated classes, the Giraffe among mammals and *Acidaspis* among Arthropods may be selected. The Giraffe represents the continuance of a very primitive type of horn; namely, one covered with a hairy skin. They are never shed, and are common to both sexes. Out of this type, all others found among the Mammalia have probably been developed. The point of interest here is that the young Giraffe is born with horns, and as these could serve no prenatal purpose, it must be concluded that the action of accelerated heredity has pushed the development of these organs so far forward as to cause them to appear during fœtal growth.

The next illustration of acceleration is taken from the Trilobites. *Acidaspis* is one of the most highly specialized and ornate genera. Although the larval forms of other genera are commonly without ornament, yet in the present genus, the protaspis, or phylembryonic, stage partakes of this specialization in so far as to develop minute spines, which later become larger, more differentiated, and form a conspicuous feature of the adult. Other characters have been likewise shown to appear at an earlier period than in other genera, and the earlier inheritance of spines must be explained in the same manner."

The facts, as stated, seem to warrant the conclusion, that in spinose organisms, the very young are almost universally without spines. Acceleration may occasionally push their development into the embryonic and larval stages, but ordinarily they are not so subject to the action of this law as are some of the physiological and other structural characters. This will be explained as in part due to the lack of general plasticity, and because differentiated spine growth is the progressive limit of variation. Therefore, there are no subsequent characters to displace them and crowd them forward in the ontogeny.

Phylogeny of Spinous Forms.

To interpret phylogeny in terms of ontogeny, according to the law of morphogenesis, or recapitulation, is perhaps easier than to trace a genetic sequence through a series of forms having a considerable geologic range. Taking the ontogenies of the animals already noticed, there is for the Pelecypods the prodissoconch, which is correlated by Jackson[55] with *Nucula*, and a Lower Silurian nuculoid radicle is assumed for the

Aviculidæ and allied forms. The first dissoconch growth produces a shell resembling *Rhombopteria*, a Lower and Upper Silurian type, and this is taken to represent the second stage in the phylogeny of *Avicula* (figure 25), *Anomia*, *Spondylus*, etc. Continuing the development of *Spondylus*, it is found by Jackson that it passes successively through stages which may be correlated with *Pterinopecten* (Devonian), *Aviculopecten* (Devonian), *Pecten* (Carboniferous ?), and *Hinnites* (Trias), while finally it assumes true spondyliform characters. These correlations agree with the geologic sequence of the genera, and are believed to indicate phylogenetic relationships. It may be further remarked that the early species of Spondyli are more truly pecteniform and hinnitiform than the later ones. The genus ranges from the Trias to the present. Zittel[73] remarks that "the oldest species are small, thin-shelled, and seldom much ornamented." Even in the Cretaceous, the majority of species are not far removed from *Pecten* and *Hinnites*. During the Tertiary, the irregular, ostræiform, squamous, concentric, and spinous growth becomes more manifest, and at present most of the species show a great development and differentiation of the spines.

Thus, while *Spondylus* is normally considered as a spinose genus and the species are familiarly known as Spiny Oysters, yet as it is traced back in geological history, the forms become less and less spinose, and their affinities and appearances are more and more in accord with non-spinose genera, until finally the prototype is a smooth, simple, delicate, unornamented shell.

The simple antlers of the young Deer and Elk correspond in type with those of the adults of the Middle Tertiary Deer (Lydekker[44]), and it may be therefore assumed that the great number of branches and tines is a modern development. Further back in the Tertiary, the ancestors of the Deer were without antlers, thus representing in phylogeny the new-born Deer of the living type. These correlations are made from comparisons of chronogenesis, or development in time, and ontogenesis, or development in the individual.

An example of a different kind will now be given to show more clearly a genetic sequence in forms. Among the Brachiopods, *Atrypa hystrix* represents one of the terminal members or species of a line of varietal and specific differentiation, extending through the Silurian and Devonian. The type commonly known as *Atrypa reticularis* appears to have had its inception during the Ordovician; yet in the Silurian, it is found as a conspicious and fully developed form. Here, also, it has quite a wide range of variation, but there seems to be an insensible

gradation between the extremes, which, therefore, cannot be considered as definite permanent varieties. There are, however, associated forms that have received distinctive specific names, which do not shade into each other. During the early and middle Devonian, certain of these variations in the main stock of *A. reticularis* became more fixed, and at the time of the Hamilton sediments in New York, there are two forms known as *A. reticularis* and *A. aspera*, which apparently do not pass into each other. As time went on, these two types became more specialized and the divergence correspondingly increased, until in the Upper Devonian, in the Chemung sediments, there is a large many-plicated *A. reticularis*, as well as a form with very few plications and long marginal spines, *A. hystrix*. Hall and Clarke[71] thus summarize the stages leading to the formation of the spinose forms: "In the variant of *Atrypa reticularis*, occurring in the Niagara fauna at Waldron, Indiana, the free concentric lamellæ frequently show a tendency to fold inward at the summit of the principal plications. The infolded edges fail to unite, and this tendency to the formation of tubules is apparently carried no further at this period. More extreme results were attained by the *Atrypa aspera* of the Hamilton shales, or possibly by its migrated ancestor, during the period of time represented by the deposition of the Lower Helderberg, Oriskany, and Upper Helderberg sediments. At all events, the *Atrypa spinosa* of the Hamilton shales is but an *A. aspera* with the lamellæ enfolded into tubular spines. Intermediate stages connecting these different phases are not present in this fauna." . . . . "This spinose form is continued into the Chemung faunas (*A. hystrix*), with some modification of expression, the spines being few and long, and the plication of the surface very coarse and quite simple; the shell in its decline thus representing a decided return to the primitive type of structure." H. S. Williams[72] has classified the variations in the stock of *A. reticularis* as to whether differentiation in the number of plications is increased or retarded, and concludes that the extremes are most strongly expressed at the close of the life-period of the race. The numerously plicated type represents the accelerated phase of the multiplication of radii, while *A. hystrix*, with its few and coarse radii, represents the retardation or suppression of this tendency.

The only great group of animals receiving its name from its characteristically spinose surface is the Echinodermata, or the spiny-skinned animals; yet it is extremely doubtful whether this name would have been used had the first studies of the group been based upon the Paleozoic representatives,

especially the pre-Devonian species. The early Sea-lilies (Crinoidea), Cystideans (Cystoidea), Blastoids (Blastoidea), and Star-fishes (Asteroidea) had smooth or nearly smooth integuments. In its early genera, even the most typically spiny class of the whole sub-kingdom, the Echinoidea (Sea-urchins) had very minute and insignificant spines. It is only in the late Devonian and in the Carboniferous that truly spiny forms of Crinoids, Star-fishes, and Sea-urchins are found.

Of equal significance is the fact that the Echinodermata together with the plants represent the most primitive type of structure, one in which there is a more or less circular arrangement of the parts or organs. The Echinodermata are the highest development in this line of growth among animals. They culminated in past geological ages, and from them no direct line of descent can be traced (Bailey[2] and Cope[11]).

The conclusion from the study of the phylogenies of spinose forms is parallel to the one drawn from the ontogenies; namely, that the ancestors of spinose as well as non-spinose organisms were simple and inornate.

[To be continued.]

Art. II.—*Electrical Discharge from the point of view of the Kinetic Theory of Matter;* by J. E. Moore.*

Part I.—On the Nature of Discharge Streams.

§ 1. *Introductory Remarks.*

It is proposed in the present paper to consider some notions concerning the elementary nature of electrical discharge in gases, which are almost wholly dependent upon the kinetic theory of matter.

However, before beginning, I wish to state that, as these notions are not in all respects in complete agreement with conclusions reached by some of the Continental and English physicists, I desire to bring them forward with considerable reserve, and with the greatest deference to the opinions of those eminent physicists, who having, perhaps, worked under different conditions, look upon these matters somewhat differently.

In order that these notions may be presented in their more general relation to phenomena, other than those of electrical discharge in gases, it is desirable to review briefly some well known facts.

In the first place it may be mentioned that the physical state of a body of gas is completely defined when we know, for that gas, its (internal) energy, entropy, volume (of a definite mass of the gas), pressure, and temperature. Three of these thermodynamic variables can be, and properly are, regarded as dependent upon the other two. So that the physical state of a body of gas is said to depend only upon its temperature and pressure.

If it be possible to consider electrical discharge through a gas as a function of the thermodynamic variables of that gas it must necessarily follow, that the phenomena of electrical discharge will be found to be dependent only on the temperature and pressure of the gas; or, since in almost all electrical experiments the temperature is kept constant, for this functional relation to exist, electrical discharge phenomena must be found to be dependent only on the pressure (or the molecular density) of the gas. This, as is well known, is actually the case. So that if we place a pair of electrodes in such a gas as air, at atmospheric pressure, discharge can only take place between them disruptively; and, as the pressure of the gas is made to vary continuously, the phenomena of electrical discharge are seen to vary continuously from disruptive discharge at atmos-

* Part I presented to the Faculty of Princeton University for the degree of Doctor of Science, June, 1898.

pheric pressure, to the total cessation of discharge at the lowest pressures attainable.

It is not intended in this paper to describe in detail the constantly changing phenomena accompanying electrical discharge, as the pressure of the gas is made continuously to vary. It may be stated, however, that disruptive discharge ceases at a pressure only a little below atmospheric, and, at a pressure of a few centimeters of mercury, the discharged path is seen to be broken up into a series of dark and bright striæ. It is worthy of special mention that the pressure at which this stratification phenomenon makes itself apparent in any particular tube, depends only on our ability to separate (optically) a bright and a dark line, and that, with steady potential differences, one can distinguish the striæ much earlier, by using a proper magnifying glass. This fact will be considered more fully farther on. The distance between consecutive striæ increases continuously, while the bright and dark bands broaden until (in a tube with fixed electrodes), the bright band of the last remaining stria comes to coincide with one electrode, and the dark band with the other.

Almost immediately after the disappearance of the stratification phenomenon, a column of blue light is seen to proceed from the negative electrode. At its first appearance, this cathode stream covers the whole surface of the negative electrode, but, as the pressure of the gas is reduced, the area covered becomes less and less, until finally, at a pressure something less than one-millionth of an atmosphere, not only has the stream come to cover a vanishingly small area of the negative electrode, but the blue light, by which the cathode stream is characterized, has totally disappeared.

With only an ordinary mercury pump we can reduce the pressure of the gas much lower than that at which the cathode stream disappears. On this further reduction of the gaseous pressure, the fluorescence of the glass walls, as well as all other evidence of electrical discharge, gradually vanishes. By absorbing the residual gas by chemical or mechanical means, such low pressures can be obtained that even though the electrodes are only a few millimeters apart no discharge can be made to pass between them, when their potential-difference is so great as to be capable of causing a spark twenty-five or thirty centimeters long in air.

By reasoning on these limiting values of electrical discharge precisely as we reason on the limiting values of functions generally, it would seem to be abundantly evident that, in space void of matter (that is in free ether), electrical discharge through that space must be zero for all possible values of the potential-difference between the electrodes.

In order to consider the character of electrical discharge phenomena a little more fully at the superior limit of pressure (or molecular density), it may be permissible to state again that the pressure at which the stratification phenomenon makes itself apparent, depends only on our ability to distinguish a dark from a bright line; that these striæ widen and grow farther apart as the pressure of the gas decreases, and conversely, become finer and more closely crowded together as the pressure of the gas increases. So that if a tube, in the stratification state, transmitting electrical discharge, have the pressure of the gas continuously increased, from a pressure at which the striæ are plainly visible to a pressure at which they can no longer be seen, one would admit that electrical discharge takes place by the same mechanism in the last state as when the striæ were visible. If the pressure be increased to atmospheric, and the discharge take place disruptively, we would admit that the type of transaction is the same as in the stratified discharge. Likewise, if we compress the gas to a liquid (and that liquid be a conductor), from considerations of the continuity of the gaseous and liquid states of matter, we ought to expect the type of transaction to remain unchanged. Finally, if we change the liquid to a solid (and that solid be a conductor), the same considerations as above would lead us to believe that conduction through this solid takes place by a type of transaction represented by stratified discharge in gases.

From this brief, general view of electrical discharge phenomena, several facts would seem to be indicated. First, that electrical discharge through a gas is primarily a transaction in that gas, and ought, therefore, to be studied from the standpoint of gas theories. Second, that the general type of electrical conduction is represented in the stratification phenomenon. Third, that the elementary mechanical actions in electrical discharge can best be studied in discharge streams. Fourth, that the study of the elementary mechanical transactions in electrical discharge is not a study merely of some interesting light phenomena, but rather a study of the elementary actions in electrical conduction, not only in gases, but in liquid and solid conductors as well.

§ 2. For a long time it has been well known that a most remarkable similarity exists between thermal and electrical phenomena. Some of the most important laws and theorems in electrical science have been developed from, or suggested by, the appropriate thermal analogies. Many instances might be cited, but one of the most striking, as well as one that illustrates how completely, even in very complex cases, these analogies hold, is the adaptation by Lord Kelvin of Fourier's solu-

tion for the flow of heat in an infinite cylinder, to the problem of the variable electric flow in submarine cables.

The mathematical theories of heat and electricity are identical in form, so that one can pass from a given theorem in the theory of heat to the corresponding theorem in electricity, by merely changing such quantities as temperature to potential, thermal conductivity to electrical conductivity, etc.

The comment that has always been made on this remarkable correspondence is, that it seems highly probable that these analogies are consequences of hitherto undiscovered relations existing between the two classes of phenomena.

The kinetic theory of gases rests upon two fundamental hypotheses. First, that matter is not a continuous plenum, but that it is made up of minute, discrete parts, which are in constant agitation. Throughout the kinetic theory, these parts are called molecules; but it is clearly stated that they are not necessarily "chemical molecules." Second, that these molecules repel one another with a force, acting in the line of their centers of gravity, whose magnitude depends upon the mass of the molecules, and on some function of the distance between their centers. In some cases, the equivalent of this last hypothesis, viz: that molecules are hard, perfectly elastic spheres, has been used to establish theorems in the kinetic theory.

From these two hypotheses, Clausius, Maxwell, Reynolds, and others, have deduced, by ordinary processes of rational mechanics, almost all the known properties of gases. Thus, according to the kinetic theory, the pressure in a homogeneous gas, at uniform temperature, is $\frac{1}{3}\rho v^2$, while its temperature is kmv^2; where ρ is the gas density, v the mean velocity of the gas molecules, m the mass of the molecules (supposed all the same), and k a constant depending on the gas.

§ 3. Maxwell has considered, in his paper, "On the Dynamical Theory of Gases,"* the pressures due to the motion of a medium composed of moving molecules. His argument is briefly as follows:

Let the medium move, with reference to a fixed system of rectangular coördinates, so that the velocity of flow referred to the three axes shall be u, v, and w. Let a second system of rectangular coördinates move with the medium, with velocity, u, v, and w. Call ξ, η, and ζ the component velocities of the motions of agitation of any molecule, when referred to this second system. The actual velocity of any molecule at any instant will then be $u+\xi$, $v+\eta$, and $w+\zeta$. The pressures in the moving medium will then be, as Maxwell has shown,

* Phil. Trans. Roy. Soc., vol. clvii, p. 49.

$$1.\quad \begin{cases} P_x = \rho u^3 + \overline{\rho\xi^2} + \rho uv + \overline{\rho\xi\eta} + \rho uw + \overline{\rho\xi\zeta} \\ P_y = \rho vu + \overline{\rho\xi\eta} + \rho v^3 + \overline{\rho\eta^3} + \rho vw + \overline{\rho\zeta\eta} \\ P_z = \rho wu + \overline{\rho\xi\zeta} + \rho wv + \overline{\rho\eta\zeta} + \rho w^3 + \overline{\rho\zeta^2} \end{cases}$$

Where – above quantities signifies mean values. If we consider the gaseous medium to move parallel to the axis of X, then $v = w = 0$, and the above equations for pressure take the simplified form :

$$2.\quad \begin{cases} P_x = \rho u^2 + \overline{\rho\xi^2} + \overline{\rho\xi\eta} + \overline{\rho\xi\zeta} \\ P_y = \quad \overline{\rho\xi\eta} + \overline{\rho\eta^2} + \overline{\rho\zeta\eta} \\ P_z = \quad \overline{\rho\xi\zeta} + \overline{\rho\eta\zeta} + \overline{\rho\zeta^2} \end{cases}$$

If $\overline{\rho\xi\eta}$, $\overline{\rho\zeta\eta}$, etc., be small in comparison with $\overline{\rho\xi^2}$, etc., and we put

$$3p = \overline{\rho\xi^2} + \overline{\rho\eta^2} + \overline{\rho\zeta^2}, \text{ equation 2 becomes,}$$

$$3.\quad \begin{cases} P_x = \rho u^2 + p \\ P_y = P_z = p \end{cases}$$

This last equation plainly shows that when gaseous matter moves in a stream in any definite direction, say that of X, the pressure of the gas in that direction is increased by an amount proportional to the square of the velocity of translation.

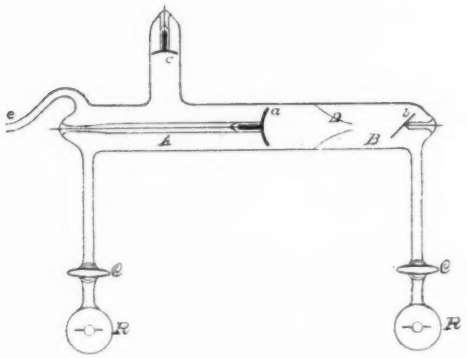
§ 4. If, in electrical discharge through a gas, the discharge stream be a stream of gaseous matter, it should be found, according to the above consideration, that the pressure in the direction of discharge is greater than in either of the directions at right angles, by an amount depending upon the velocity of the discharge stream.

In order to determine whether or not this inequality of pressure actually exists in a gas transmitting electrical discharge, an experimental tube, as described below and illustrated in figs. 1 and 2, was made.

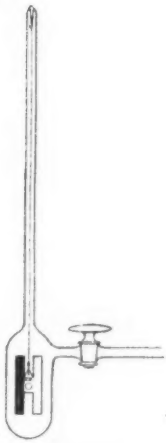
As shown in fig. 1 (p. 26), the tube is of cylindrical form, about 33^{cm} long, and $3{\cdot}6^{cm}$ internal diameter. It is provided with three electrodes, but in the experiments to be described, only the electrodes (*a*) and (*b*) are used. (*a*) is an aluminum electrode of spherical form, $2{\cdot}8^{cm}$ in diameter, having a radius of curvature of $2{\cdot}5^{cm}$. (*b*) is a plane platinum electrode. (D) is a funnel-shaped glass diaphragm sealed to the walls of the tube around its base and having an opening of about $\cdot5^{cm}$ at its apex. (R, R) are two similar radiometers, communicating with spaces (A) and (B) of the tube respectively ; the connecting tubes from the radiometers are provided with stopcocks (C, C). One

of the radiometers is shown in detail in fig. 2. The movable vane consists of an H-shaped piece of clear mica. The two vertical members are lampblacked on opposite sides. The radiometer vane is provided with a mirror for reading angular deflections and a small magnet to give it directive force; the whole system is supported by a single cocoon fiber attached to a hook at the upper end of the suspension tube. The tube (*e*) leads to a mercury pump.

1.



2.



The radiometers (R, R) are employed for the purpose of measuring the pressure in the regions (A) and (B) respectively of the tube, and in this way serve as means for indicating whether or not, during electrical discharge, the gaseous pressures in these regions become different.

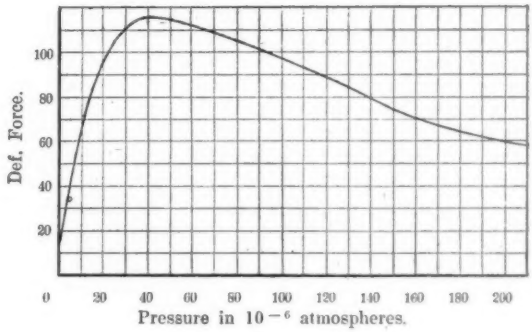
That the deflecting couple acting on a given radiometer vane (when a constant light source is used) may be taken as an indication of the pressure (or molecular density) of the gas within the containing vessel, has been shown experimentally by Crookes* and is a direct consequence of the beautiful theory of the radiometer as given by Reynolds†. Without considering the theory of the radiometer at this point, the relation existing between the gaseous pressure within the radiometer vessel and the deflecting couple acting on the radiometer vane, produced by a constant light source, is clearly shown by fig. 3, which is taken from Crookes's paper just cited.

* On Repulsion resulting from Radiation, Phil. Trans., Roy. Soc., vol. clxx, Pt. I, p. 87.

† Dimensional Properties of Matter in the Gaseous State, Phil. Trans. Roy. Soc., vol. clxx, Pt. II, p. 727.

The radiometers in the present instance were designed to be used at pressures corresponding to points lying on the sensibility curve between maximum and zero deflecting forces. The

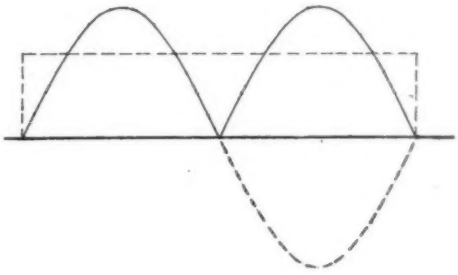
3.



reason plainly being, that on this branch of the curve $\frac{dF}{dP}$ has its maximum value,—F being deflecting force and P pressure.

On account of the somewhat uncertain, as well as intermittent character of the potential-difference produced by an induction coil actuated by a make and break in the primary circuit, it has been found most desirable and useful to employ an alternating current, varying as a simple harmonic function of the time, in the primary of the induction coil. The potential-difference thus induced in the secondary circuit is alternating

4.



in character. By employing a two-part commutator, driven by a synchronous motor, the alternating potential-difference is rectified as shown by waves above the abscissas line in fig. 4.

As the secondary of the induction coil is short circuited twice during each rotation of the two-part commutator, the potential-difference at the terminals of the secondary must be zero at the instant of short circuit, to prevent serious sparking at the contact brushes. This adjustment is easily made, and serves as a delicate means to determine when one of the electrodes of a tube, connected to the terminals of the commutator, is at every instant, throughout the waves of potential, positive, and the other electrode, at every instant, negative.

The tube, being connected to the mercury pump, is levelled and otherwise adjusted until the radiometer vanes hang centrally in their containing vessels. The whole tube is then thoroughly exhausted and dried, (the glass stopcocks C, C, fig. 1, being open). A separate light source of constant illumination is provided for each radiometer. Incandescent lamps have been found most desirable for this purpose. An image of the filiment of the incandescent lamp, as reflected from the concave mirror on the radiometer vane, is received on a white graduated scale, located between the radiometer and the light source. The pressure of the residual gas in the tube is then adjusted, by means of the mercury pump, until any further reduction of the pressure decreases the deflection of the radiometer vane. One can in this way be sure that the pressure in the tube corresponds to some point on the descending branch of the sensibility curve.

The tube is then left connected to the mercury pump, and the uni-directional potential-difference, obtained as described, is connected to the electrodes (*a*) and (*b*), fig. 1,—(*a*) being made negative, (*b*) positive. At the pressure above indicated (about $10 . 10^{-6}$ Ats.), a clean cut discharge stream is seen to go out from the negative electrode (*a*), pass continuously through the opening in the funnel-shaped diaphragm (D), strike the positive electrode (*b*), and cause fluorescence on the glass walls of the tube back of (*b*), not shielded by the electrode. The glass stopcocks (C, C) are now closed, the induction coil and the rotating commutator are thrown out of action. The images of the incandescent lamp filiments on the graduated scales are allowed to come to rest. The stopcock of the radiometer on the B-side of the diaphragm (D) is then carefully opened. The deflection of the radiometer, as indicated by the reflected image of the incandescent lamp filiment, is seen permanently to decrease. The change in deflection on opening the cock amounted in some experiments to as much as 10^{cm} when the scale was 75^{cm} from the radiometer. On opening the cock connecting the radiometer, on the A-side of the diaphragm, with the tube, very little change of deflection is noted. This is readily understood when the relative

volumes on the two sides of the diaphragm (D) are considered. The whole exhausted system of the mercury pump is in connection with the region (A) of the tube. The volume of the pump system is two or three times greater than the whole volume of the tube. So that the indication of the second radiometer merely shows that no measurable reduction in the gaseous pressure on the A-side of the tube occurred during discharge. This experiment was repeated many times, and at different pressures. In every case the indication of the radiometer on the B-side of the tube showed a decrease of pressure when its stopcock was open, so that it was put in communication with the rest of the exhausted system. In no case was there any considerable change of deflection noticed in opening the cock of the radiometer on the A-side of the tube.

When the gaseous pressure in the tube is very much higher than that at which the radiometers can be used to advantage to measure differences of pressure, if a discharge be sent through the tube by means of the above described uni-directional potential-difference, a discharge stream is seen to proceed from the cathode and continue on its course to within a short distance of the opening in the funnel-shaped diaphragm. Here the discharge stream seems to end in a bright band, and from this point on, in the region (B), striæ are seen to succeed one another, as in the stratification phenomenon. The tube in this state transmits discharge through the region (A) by the discharge stream, and through the region (B) by the stratification process. As discharge stream and stratification phenomena are characteristic of different gaseous pressures, this last experiment is in agreement with the experiments described in the preceding paragraph.

Not being provided with a McLeod gauge, or other reliable means of measuring low gaseous pressures, it is impossible to state with accuracy the absolute value of the change of pressure observed by means of the radiometers in the previous experiments. However, the pressure at which the radiometers gave their maximum deflection could not have been far from $50 . 10^{-6}$ Ats., and the pressure at which the first set of the above experiments was made could not have been far from $10 . 10^{-6}$ Ats. The spot of light from the radiometer connected with the B-side of the tube at the above pressure, fell at 80 or 90^{cm} from zero. It seems probable, therefore, that the change of pressure observed amounted to more than 10 per cent of the uniform pressure of the tube.

The above experiments would seem to be in good agreement with the considerations in § 3 on the pressure resulting from the motion of a gaseous medium. So that in the above experiments, region (B), into which a discharge stream passes,

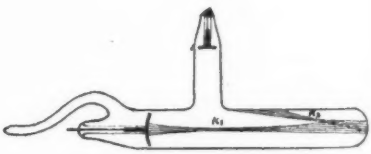
being uniformly at a higher pressure (or molecular density) than region (A), from which the discharge stream comes (on account of the law of the conservation of matter), one would apparently be making no mistake in concluding that the discharge stream must convey gaseous matter from region (A) to region (B).

§ 5. In the foregoing considerations and experiments on discharge streams, attention has been almost wholly directed to the discharge stream from the cathode. But if discharge streams are streams of gaseous matter (unless there be a continuous accumulation and rarefaction of the gaseous medium as long as the discharge stream flows), then, according to the law of the conservation of matter, there must be found to be secondary streams, which serve as return streams in the circulation of the gaseous medium. These secondary streams have, in reality, been found to exist.

It is a fact generally observed, in tubes intended for the generation of Röntgen rays, that the glass walls of the tube in front of the electrode struck by the discharge stream from the cathode, fluoresce vigorously. This fluorescence of the walls of the tube is sharply limited (in case of a plane electrode) by the line of intersection of the plane of the electrode with the walls of the tube. If we make the electrode cylindrical in form, the fluorescence of the glass walls is no longer of uniform brilliancy, but appears as a bright line or band on those portions of the tube lying in the direction of the center of curvature of the cylindrical electrode. If, instead of making the electrode cylindrical, we make it of spherical form, the fluorescence of the glass walls no longer shows as a line or band, but as a bright, sharply defined circular or elliptical spot of light, according to the angle of inclination of the axis of the spherical electrode to the glass wall where the fluorescent spot occurs.

5.

6.



Of the numerous tubes that have been made for the purpose of studying these secondary discharge streams only two will be described at this point. Fig. 5 represents a simple cylindrical tube, provided with two precisely similar spherical aluminum electrodes, of $2{\cdot}5^{cm}$ radius of curvature and $2{\cdot}7^{cm}$ in diameter.

The internal diameter of the tube is $3{\cdot}5^{cm}$ and the two spherical electrodes are $7{\cdot}5^{cm}$ apart.

At comparatively high pressures, and with the ordinary contact maker in the primary, two discharge streams can be distinguished, of almost equal intensity. But if contact be made and broken very slowly, it is seen that these two streams are not simultaneous phenomena, one being produced by the potential-difference at make, and the other at break of the primary circuit. By decreasing the pressure in the tube continuously, one of these streams is seen gradually to grow smaller, and finally entirely to vanish.

On further decreasing the pressure, until the discharge stream from the cathode covers but a small portion of the total area of the cathode a secondary stream from the anode is found to exist, whether we allow the coil to work continuously, or examine the discharge at each make and break of the primary. At make, no discharge stream is seen from either electrode, but at break, the two streams (one from the cathode, the other from the anode) can easily be separated by a magnet, as shown in fig. 5. In some of the early tubes made for the study of these secondary streams, the spherical anode was turned through a small angle, so that the discharge stream from it ordinarily fell on the glass wall of the tube. In this way the two discharge streams can easily be seen, without it being necessary to separate them by a magnet. These experiments have also been performed with the rectified alternating potential-difference, described in § 4; the same evidence of secondary streams as just noted has, in every case, been observed. This experiment will be further discussed in part II of the present paper.

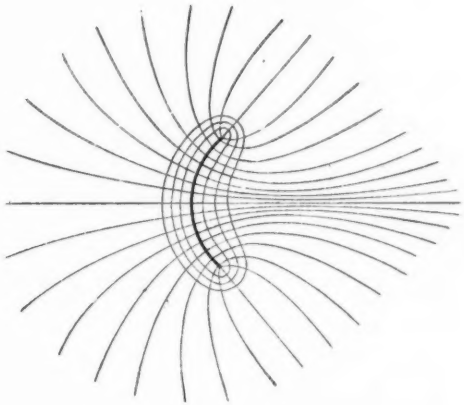
Fig. 6 illustrates a tube that shows these secondary discharge streams under conditions somewhat different from those in the tube just described. The tube has two spherical aluminum electrodes each of $2{\cdot}5^{cm}$ radius of curvature; the electrode in the main tube being 2^{cm}, that in the branch tube $1{\cdot}7^{cm}$ in diameter. The diameter of the main tube is $2{\cdot}5^{cm}$, that of the branch tube at right angles, $1{\cdot}8^{cm}$. The distance between the electrode in the main tube and the opposite glass wall is about 14^{cm}.

At a pressure considerably lower than that at which a discharge stream is sent through the tube on the make of the primary, there is seen to spring from the spherical formed end of the glass tube lying opposite the cathode, a secondary stream, (k_2) in fig. 6. This secondary stream could be deflected by a magnet, caused fluorescence of the glass walls where it struck, and in all other respects acted as a discharge stream would have acted, coming from a cathode located at the end of the glass tube.

The above described experiments would seem to demonstrate the reality of the secondary discharge streams indicated by the kinetic theory. The experiments also show that these secondary streams do not take definite form until the pressure of the gas (compared with atmospheric pressure) is very low. This, according to the kinetic theory, is what ought to be found.

To examine the kinetic theory, as developed to explain the conduction of heat through gases, for the purpose of determining whether or not this theory can be employed to render an account of the form and action of discharge streams, it will be necessary to call attention to the heat-flow lines from a hot body immersed in a cool gas. Consider a spherical cup at a uniform temperature, higher than that of the surrounding gas, and at great distance from any other solid body. Heat will flow from the spherical body to the surrounding gas along lines at

7.

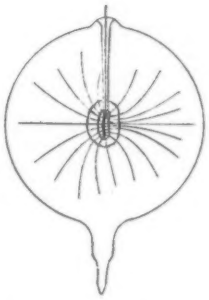


every point normal to surfaces of equal temperature. Thus these heat-flow lines will spring from all points on the spherical surface, normal to the surface at the point of departure. Calling ds an element of the surface of the spherical body, n a normal to the element at its central points, and θ the temperature, then the quantity of heat conducted from this element in unit time, is $k\frac{d\theta}{dn}$; where k is a constant, depending on the nature and state of the gas. If we now define n as the normal to any isothermal surface surrounding the spherical cup, and so choose ds that $k\frac{d\theta}{dn}ds = 1$, we can divide the whole space

surrounding the heated body into unit heat-flow tubes. The central line or axis of each of these tubes, defined as above, may be taken as unit heat-flow lines. These heat-flow lines from a spherical cup, drawn as just indicated, are shown in fig. 7.

The appearance of these heat-flow lines at once reminds us of the form of a discharge stream from a spherical cathode, even in a narrow tube. In order to compare the form of a discharge stream from a spherical electrode, with the heat-flow lines from such a body, conditions, similar to those under which the flow lines illustrated in fig. 7 are supposed to exist, must be chosen. For this purpose, the large bulb illustrated in fig. 8 was constructed. This bulb is, as nearly as may be, a sphere of about 15^{cm} diameter. At the center of the spherical bulb is placed a spherical aluminum electrode of 2·5^{cm} radius of curvature, and 1·85^{cm} in diameter. The electrode is connected by a platinum wire to the outside of the bulb.

8.



After exhausting the bulb to a comparatively low pressure, the spherical electrode is connected to one terminal of a spark gap in the secondary circuit of an induction coil. The whole surface of the electrode appears to take part in the action of discharge, and, at pressures not too low, no very well-defined stream can be distinguished. The appearance of the blue discharge is roughly sketched about the electrode in fig. 8. While those portions of the discharge, from the concave side of the electrode in the direction of the axis of the electrode, appear more dense, yet there is no indication of a "focusing" of the discharge at the center of curvature of the electrode. As the pressure is progressively decreased, the general blue discharge from the convex side of the electrode, as well as from the edges and outside portions of the concave side, becomes fainter in comparison with the discharge from the central portion of the concave side of the electrode. The glass walls facing the convex side of the electrode appear to fluoresce almost uniformly; the fluorescence of the walls facing the concave side, falls off very abruptly from the point of intersection of the axis of the electrode with the walls of the bulb. The fluorescence of the bulb on the concave side, at very low pressure, appears as a bright spot (not very sharply defined), at the intersection of the axis of the electrode with the walls. At

this pressure, the discharge producing visible effect in the gas, is almost wholly confined to the concave surface of the electrode. This discharge stream is seen to be affected by a magnet, causes fluorescence of the glass walls, and electrifies the glass walls where it strikes, precisely as a discharge stream from a cathode, in a "conduction tube"; and this, whether the electrode be connected to one or the other side of the spark gap. The above observations have been repeated, with the uni-directional potential-difference described in an earlier paragraph, with the same results as are here given.

In the case of the heated spherical cup, previously considered, the quantity of heat conducted, in unit time, across any isothermal surface limited by any unit heat flow tube, is, by the kinetic theory, $\frac{1}{2}Nmv^2$; N being the number of molecules crossing the surface in one second, in the direction in which heat flows, in excess of the number crossing the surface in the opposite direction, v the mean velocity, and m the mass of the molecules. But $Nm \propto \rho$, the gas density; and $\frac{1}{3}\rho v^2 = p$, the pressure of the gas. So that the heat-flow lines, shown in fig. 7, may be taken to represent the normal component of the pressure brought into existence in the gaseous medium by the operations of heat conduction. Plainly a family of surfaces, over each of which the gaseous pressure has a constant value, can be described about the heated body. These surfaces cut the pressure or heat-flow lines orthogonally, and appear, in a meridian section, as lines everywhere normal to the heat-flow or pressure lines. A few of these lines are shown in fig. 7. The form of these surfaces is practically identical with that of the "dark space," as it recedes from the cathode when the pressure of the gas is reduced.

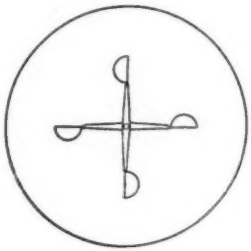
From the description of the method of drawing the heat-flow or pressure lines, shown in fig. 7, it will be clear that the space rate of variation of pressure outwards, from the heated surface, is a direct function of the angular divergence of the heat-flow lines. Accordingly, as Professor Reynolds* has pointed out, the reaction of the gaseous medium on the convex side of a heated spherical cup ought to be greater than on the concave side. Two such cups ought to rotate, with their concave sides forward when properly pivoted in a rarefied gas, and brought to a higher temperature than the surrounding gas. This they are observed to do in Crookes' cup radiometer.

It was thought worth while to determine whether or not similar reactions could be observed, when the spherical cups instead of being heated, were brought to a high electrical po-

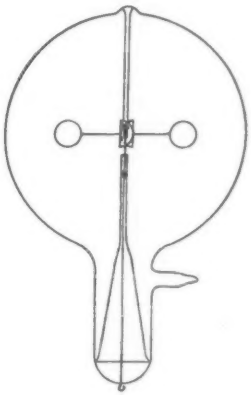
* Cf. note, p. 26.

tential. In order to carry out this experiment, the bulb shown in figs. 9 and 10 was constructed. A spherical bulb, 10·8^{cm} in diameter, has pivoted on a needle point at its center, a system of four very light spherical aluminum cups, held by four arms going out from a steel pivot, as is shown in fig. 9. These

9.



10.



cups are nearly hemi-spherical and are about ·5^{cm} radius of curvature. The needle point is connected by a platinum wire to the outside of the tube.

When the bulb is thoroughly exhausted by means of a Sprengel pump, the movable system is put in connection with one terminal of the two-part commutator for rectifying the alternating potential-difference of the secondary of the induction coil as described in an earlier section. The cups are seen to rotate, concave side forward. On disconnecting the electrical source, and grasping the bulb in the hands, the cups immediately begin to rotate in the opposite direction and continue to rotate for a short time before coming to rest. The electrification of the walls is very troublesome, but when they are carefully discharged after each operation, the above direction of rotation, upon connecting the movable system with a source of high potential, has been observed, whether the potential of the source be positive or negative in sign.

§ 7. On considering the heat-flow lines from the surface of a hot body immersed in a cool gas, it is clear that the shape of the lines of flow will be affected by the distribution of temperature on opposing or neighboring surfaces. Thus, in fig. 7, if the spherical cup be placed in a closely fitting cylinder, whose walls in the vicinity of the cup, are at a temperature but slightly different from that of the spherical cup, the

distribution of the flow lines will be very much modified. Although the actual determination of the lines of flow would be a somewhat complicated problem, yet it is quite plain that the lines of flow in the region of the edges of the spherical cup would almost wholly vanish, and that the lines from the central portion would appear more crowded together. If beside the cylinder surrounding the spherical cup and heated near the cup, there be a region of very low temperature opposite the concave side of the cup, the lines of flow from the central portion of the cup will be still more condensed. It is also clear that if the gaseous medium in the vicinity of the spherical cup, move in streams from the walls of the surrounding cylindrical surface towards the spherical cup, with very considerable velocity, this motion of translation of the medium will also affect the form of the heat-flow lines from the spherical surface. When this velocity of the medium becomes equal to the velocity of the molecules transmitting heat along the flow lines, then those flow lines where this equality occurs will vanish.

The above considerations relating to the modification of heat-flow lines for a hot body immersed in a cool gas, plainly suggest causes for the remarkable diminution of size and change of form of a discharge stream from the cathode in an ordinary discharge tube, as the pressure of the gas is reduced.

The considerations, and the experiments described in § 5 made it appear that a discharge stream from a cathode is but one part of the cycle performed by the gaseous medium in the operation of transmitting electrical discharge by discharge streams. The energy transmitted by these streams, being dependent on the number and velocity of the molecules forming the streams, it is clear that, as the pressure or molecular density of the gas is reduced, the velocity of translation of the molecules throughout their cyclical course, must increase, in order to transmit the same energy. It thus appears that the velocity of flow of the gaseous medium in the return stream to the cathode, increases as the molecular density of the gas decreases. It was also shown in § 5, that secondary discharge streams can spring from regions electrified by discharge streams from the cathode; and one ought to expect these secondary streams to spring from surfaces electrified in any other way. That the walls of a discharge tube near the cathode are electrified there can be no doubt, for not infrequently the glass walls of the tube break down at this point under the electrical stresses, when the pressure of the gas is very low. It ought thus to be found (due to the electrified walls near the cathode acting as sources of secondary discharge streams), that the stream from the cathode dimin-

ishes in cross-sectional area much more rapidly with pressure, in tubes whose walls lie very near the cathode, than in those whose walls are far removed from the cathode. It ought also to be found that the form of the discharge stream from the cathode is modified by the form of the glass walls near the cathode.

The return stream from the walls of the tube to the cathode, indicated in the foregoing paragraphs, can be observed, during the process of exhaustion, in almost any tube. When the pressure of the gas is such that the discharge stream from the cathode no longer covers the whole area of the electrode, there can clearly be seen a convergent band, or collar of light, beginning near the walls of the tube in the vicinity of the cathode and extending to the base of the discharge stream. The general appearance of this return stream to the cathode is shown in fig. 11 for a spherical electrode. For clearness only

11.

the meridian section of the streams is shown. As the pressure in the tube is decreased, the return stream appears to spring from points on the walls more remote from the cathode; the pink light, by which the return stream is distinguished, becomes fainter, and long before the disappearance of the discharge streams from the cathode, all visible evidence of this return stream has vanished.

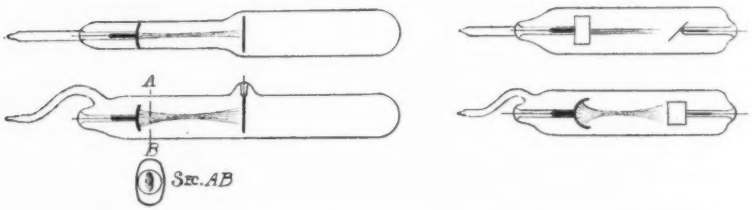
For the purpose of illustrating the variation of the action of the walls of a tube with their distance from the cathode, in decreasing the cross-sectional area of the discharge stream from the cathode, the tube illustrated in fig. 12 was constructed.

12.

As will be seen from the figure, it is formed of two cylindrical glass tubes of very different diameters. The large tube is about 4·6^{cm}, and the smaller 1·85^{cm} in diameter. The two spherical aluminum electrodes are each 1·8^{cm} diameter, and 2 5^{cm} radius of curvature. The distance between these electrodes is about 20^{cm}. When the pressure in the tube is not

very low, and (*a*) is the cathode, the discharge stream from (*a*) covers the whole surface of the electrode. The "dark space" still appears around the electrode at about 3^{cm} from it on the concave side. On making (*b*) the cathode, a sharp, very well defined stream is seen to spring from it, and there is no appearance of the "dark space" about the electrode. At this pressure, the area of the electrode (*b*), covered by the discharge stream, is only a small fraction of the total area of the electrode. The walls of the tube being cylindrical, the stream is of circular cross-section, and springs from the portion of the electrode lying immediately around the point of intersection of the axis of the tube with the electrode. As the pressure in the tube is gradually decreased, the area of the electrode covered by the discharge stream from it becomes less and less, until the stream totally disappears. At this pressure, upon making (*a*) negative, the discharge stream from it still covers a considerable portion of the electrode. At very low pressure, discharge can be sent through the tube by making (*a*) the cathode, but cannot be made to pass, with the same potential-difference, when (*b*) is made the cathode. This experiment was repeated by means of a tube identical with that shown in fig. 12, excepting, in place of electrode (*a*), is substituted one whose diameter is just equal to the internal diameter of the large tube, and whose radius of curvature is 3·75^{cm}. The dis-

13. 14.



charge stream from the large electrode when it is negative is much more clearly marked than the discharge stream from cathode (*a*) in the tube shown in fig. 12. This is due to the fact that in the last tube all disturbance arising from discharge from the convex side of the electrode is avoided. The same description of the inequality of cross-section, and final vanishing, at extremely low pressure, of the discharge streams from the two electrodes, when first one and then the other is made cathode, as given for the tube shown in fig. 12, applies to the discharge streams from the two electrodes in this tube.

To illustrate the effect of unsymmetrical walls upon the form of cross-section of the discharge stream from the

cathode, the tube shown in fig. 13 was made. It consists of a cylindrical tube $3{\cdot}5^{cm}$ internal diameter, and 25^{cm} long. The walls of the tube for about 8^{cm} in front of the cathode are flattened, so as to be elliptical in form. The cathode is a spherical aluminum electrode $2{\cdot}2^{cm}$ diameter, and $2{\cdot}5^{cm}$ radius of curvature. The anode is a plane platinum disk, placed at right angles to the axis of the tube, and 9^{cm} from the cathode.

The form of the discharge stream from the cathode is shown in the figure. When viewed from the direction of the longer axis of the elliptically-shaped walls, the discharge stream appears as a narrow ribbon, the edges being almost parallel; from a position in the direction of the shorter axis of the elliptically-shaped walls, the stream appears to cover the cathode almost to its edges. From the surface of the cathode the stream converges to a region of minimum thickness, and then diverges until it strikes the anode.

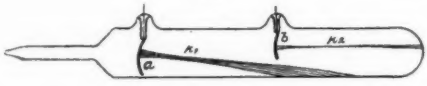
The modification of form of discharge streams, resulting from the unequal velocity of the return streams from the glass walls of the tube, may be further illustrated by the tube shown in fig. 14. This is a cylindrical tube $3{\cdot}7^{cm}$ internal diameter, and 16^{cm} long. The aluminum cathode is cylindrical in form, the radius of curvature being $1{\cdot}2^{cm}$. The dimensions of the electrode are: length parallel to the axis of the cylindrical surface, $2{\cdot}3^{cm}$; across the concave opening, $2{\cdot}4^{cm}$. The anode is a plane platinum plate set at an angle to the axis of the tube.

The return stream from the walls of the tube (traveling in straight lines) must leave the walls at a greater distance from the cathode, in order to reach the central portion of the cylindrical surface, by coming over the sides, than by entering the cathode from the ends. The electrification of the walls of the tube falling off very rapidly from the cathode, the velocity of those parts of the return stream which spring from points on the walls of the tube near the cathode, must be very different from the velocity of those parts coming from points remote from the cathode. The cross-section of the discharge stream from a cylindrical cathode ought, then, to be found to diminish more rapidly (with decreasing molecular density), parallel to the axis of the cylinder, than along the arc of the curved surface.

At its first appearance the discharge stream from the cylindrical electrode seems to spring from the whole concave surface; but as the pressure in the tube is decreased, the stream very soon grows narrow, as viewed from the side of the cathode. The stream also grows smaller along an arc of the curved surface; but its rate of decrease with pressure along the arc is at all times less than in a direction parallel to the axis. As the stream vanishes, it still covers a considerable length of the arc, while its dimension parallel to the axis is a mere line.

The importance of the return stream from the walls of a tube in determining, not only the form and cross-section of the discharge stream, but also the region of the cathode from which the discharge stream springs, is illustrated by the tube shown in fig. 15. The tube is a simple glass cylinder, about

15.



24^{cm} long and 3·5^{cm} in diameter. It is provided with two spherical aluminum electrodes, each of 2·5^{cm} radius of curvature. The electrode (*a*) is 2·7^{cm} in diameter, while (*b*) is 1·6^{cm} in diameter. The electrode (*a*) is set eccentrically in the tube, so that the edge opposite the point of support is nearly in contact with the inner surface of the glass wall of the tube. The electrode (*b*) is also set eccentrically, but in the opposite direction.

When the pressure in the tube is low, and (*a*) is made cathode, a small, well defined, discharge stream is seen to spring, not from the center of the electrode, but from the point of intersection of the axis of the tube and the electrode. The stream, springing from the electrode normally to the surface, makes an angle with the axis of the tube. As the walls are cylindrical, the cross section of the discharge stream is circular.

Finally, it may be mentioned that it has been found that the form of the discharge stream from a plane, convex, concave, or ring cathode, at a pressure just higher than that at which the stream vanishes, appears to an observer to be almost independent of the form of the electrode.

Princeton University, Princeton, N. J.

Art. III.—*The Crystalline Symmetry of Torbernite;* by T. L. Walker.

[By permission of the Director of the Geological Survey of India.]

The minerals of the Uranite group have the general formula $R(UO_2)_2M_2O_8 . 8H_2O$. where R may be Cu, Ca or Ba and M either P or As. Two of the minerals are considered to be tetragonal, and the other three rhombic, though their angles and axial relations are almost identical with those of the two tetragonal minerals.

Torbernite — $Cu(UO_2)_2P_2O_8 + 8H_2O$ tetragonal — $c = 2{\cdot}9361$
Zeunerite — $Cu(UO_2)_2As_2O_8 + 8H_2O$ " — $c = 2{\cdot}9125$

Autunite — $Ca(UO_2)_2P_2O_8 + 8H_2O$ rhombic $\dot{a} : \overline{b} : \dot{c}$ ·9875 : 1 : 2·8517

This similarity in chemical constitution combined with the close morphological affinity indicated by the axial relationships, leads one to ask whether the whole group may not be isomorphous and belong to the same crystal system. It will be generally admitted that the crystals of these minerals are seldom suitable for accurate goniometric determinations, as is evidenced by the varying results obtained by different well known observers. The measurements quoted by Dana* for torbernite vary in many cases from one to two degrees, very considerable differences when we consider its close resemblance to autunite, which is plainly not of a higher grade of symmetry than rhombic.

Brezina† examined autunite from Johanngeorgenstadt and concluded that it was monoclinic and only pseudo-rhombic. He assigned the axial relationships

$$\dot{a} : \overline{b} : \dot{c} = 0{\cdot}3463 : 1 : 0{\cdot}3525$$

We may express the same proportions by the following figures,

$$\dot{a} : \overline{b} : \dot{c} = 0{\cdot}9886 : 2{\cdot}8379 : 1$$

This brings out clearly the close relationship between the monoclinic form calculated by Brezina for autunite and the commonly accepted rhombic proportions

$$\dot{a} : \overline{b} : \dot{c} = 0{\cdot}9875 : 1 : 2{\cdot}8517$$

It is thus seen that Brezina orients the crystals so that the ver-

* System of Mineralogy, 6th ed., p. 856.
† Zeitschr. f. Kryst., iii, p. 273.

tical axis becomes the orthodiagonal and the perfect cleavage basal according to the rhombic orientation becomes clino-pinacoidal.

I give below some of the reasons which lead me to conclude that torbernite as well as autunite is monoclinic and that the uranite minerals form an isomorphous group.

1. *Isomorphism of torbernite and autunite as described by William Phillips in 1815.*—One of the first writers on this mineral group was William Phillips, who read a paper before the Geological Society of London in 1815 "On the oxyd of Uranium." His paper is accompanied by three fine plates, which make it clear that in his day autunite and torbernite had not been separated. His specimens were principally from Tol Carn and Tin Croft in Cornwall. Speaking of the color of the crystals he says: "On other specimens the crystals are transparent and of a greenish hue, whence they pass through almost every shade into deep grass green; while in others the center of the crystal is yellow and the edges only are green."* He is clearly describing crystals whose centers are composed of the yellowish mineral autunite while the green border mineral is one of the copper uranite, most probably torbernite. At that time Mitscherlich had not yet stated his Law of Isomorphism, neither does it appear that Phillips knew the essential chemical difference between the yellow and green crystals. His descriptions are of great value, for in those days excellent specimens were to be had in abundance. He says: "There are in my possession 55 specimens of oxyd of uranium from the various mines in Cornwall above cited and upwards of 200 detached portions each having one or more well defined crystals."† At present very few museums possess more than a dozen specimens all told.

If autunite and torbernite be isomorphous then what Brezina has established for autunite applies also to torbernite and it becomes probable that both minerals are monoclinic.

2. *Cleavages of torbernite.*—All the minerals of the Uranite Group have one very perfect cleavage which is parallel to the basal pinacoid according to the commonly accepted orientation of the crystals. In addition to this, basal cleavage fragments show two other fairly perfect cleavages which appear to intersect at right angles—in torbernite said to be parallel to the prism of the second order (100) and in autunite parallel to the macro- and brachy-pinacoids (100) and (010). In the latter mineral these two cleavage directions are plainly unequally developed, which is to be expected in pinacoidal cleavages of a rhombic crystal. In torbernite however the two cleavage

* Trans. Geol. Soc., vol. iii, p. 114.
† Loc. cit., p. 118.

directions are equivalent and the cleavages should be equally perfect if the mineral be tetragonal. This however is not the case. If we regard torbernite as rhombic or monoclinic this difference of cleavage would be quite regular.

3. *Evidence from Etching Figures.*—Thin cleavage plates parallel to (001) were treated for fifteen seconds with hot 5 per cent nitric acid. The operation is best performed in a porcelain dish using about 5^{cc} of the dilute acid, the action being terminated by adding 250^{cc} of cold water when the desired corrosion period is ended. After drying, the cleavage fragments were examined under the microscope and showed monosymmetric etching figures in abundance (fig. 1). These figures are symmetrical about one plane only and that plane is parallel to the better of the cleavages observed in basal cleavage fragments. This indicates that torbernite is monoclinic and that the very perfect so-called basal cleavage and the less perfect of the other two cleavages lie in the zone of the ortho-diagonal, while the third (second best) cleavage is clino-pinacoidal. It must be remarked that this orientation does not agree with that adopted by Brezina for autunite, for he finds the best or basal cleavage so-called to be clino-pinacoidal while the etching figures indicate that in the case of torbernite this cleavage lies in the orthodiagonal zone.

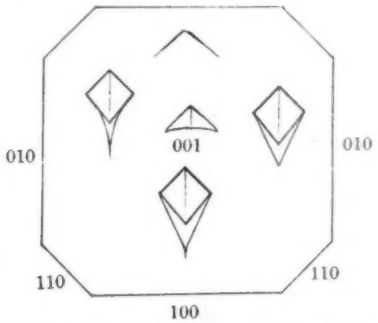


FIG. 1. Basal section of torbernite showing etching figures produced by 5 per cent hot nitric acid by 15 seconds corrosion. Figures much enlarged.

The progress of corrosion tends to obliterate the monoclinic character of the etching figures, though they never lose the habit completely. It may be stated as a general rule that corrosion figures become less plain with the progress of the reaction after a certain stage has been reached, and the chief difficulty in preparing etching figures for microscopic examination is to interrupt the reaction just when that stage of best definition is reached.

4. *Optical properties.*—Thin basal cleavage plates when viewed under the microscope between crossed nicols in convergent polarized light give a biaxial interference figure with a very small optical angle—much like those observed in many biotites. Though nearly uniaxial the biaxial character is so constant in all parts of the thin plates that by revolving till the cross is perfect it is regularly seen that the directions of the two cleavage systems and the cross hairs agree. Though the optical angle is quite small the biaxial nature of torbernite is plain—much more so than in the majority of biotites. But even if at times the interference figures were practically uniaxial, that would not be sufficient ground for retaining torbernite as a tetragonal mineral any more than the very small optical angle for biotite would justify one in maintaining that biotite is hexagonal. The case of biotite, pseudo-hexagonal in form and with very small optical angles, at times practically uniaxial and torbernite, pseudo-tetragonal in form with a very small optical angle, are quite analogous. The minerals also resemble one another in offering only poor crystals for goniometric determinations and in being plainly monoclinic when examined by means of corrosion figures.

Indian Museum, Calcutta.

Art. IV.—*Further Separations of Aluminum by Hydrochloric Acid;* by Franke Stuart Havens.

[Contributions from Kent Chemical Laboratory of Yale University—LXXI.]

In former papers* from this laboratory methods have been described for the separation of aluminum from ferric iron, and from beryllium, based on the insolubility of the hydrous aluminum chloride in a mixture of equal parts of aqueous hydrochloric acid and ether saturated with hydrochloric acid gas, the ferric and beryllium chlorides being exceedingly soluble in this mixture.

It was the purpose of the investigations herein described to discover how far this process could be extended, with certain modifications, to cover the separation of aluminum from such other metals as might occur with it, either in artificially prepared alloys or in naturally-occurring compounds.

The aluminum used in all the following experiments was in the form of a solution of the chloride. This chloride was purified, as previously described,† from iron by precipitation with hydrochloric acid, and from the alkalies by precipitation as the hydroxide and continued washing with water until the washings gave no test with silver nitrate. The hydroxide thus obtained was dissolved in hot hydrochloric acid to get it into the form of the chloride. The chloride solution was standardized by precipitating weighed portions with ammonia and weighing as the oxide.

Separation of Aluminum from Zinc.

A solution of pure zinc chloride made by dissolving metallic zinc, free from impurities, in hydrochloric acid, is not precipitated when treated with an equal volume of ether and saturated with hydrochloric acid gas.

To prepare a definite zinc salt free from traces of the alkalies which would be precipitated with the aluminum by strong hydrochloric acid, pure metallic zinc was dissolved in hydrochloric acid, the dilute solution precipitated with ammonium carbonate, and the resulting carbonate ignited to a constant weight as zinc oxide. This oxide dissolved in hydrochloric acid gave a pure chloride.

The aluminum in all these experiments was determined in the following manner:—Portions of the prepared solution of aluminum chloride were weighed in a small beaker, weighed portions of zinc oxide added and sufficient aqueous hydrochloric

* Gooch and Havens: this Journal, vol. ii, p. 416.
Havens: this Journal, vol. iv, p. 111.
† Loc. cit.

acid to dissolve it. The beaker was then cooled by immersion in an inverted bell-jar supplied with running water by means of inlet and outlet tubes, and a current of gaseous hydrochloric acid (generated by the gradual addition of sulphuric acid to a mixture of hydrochloric acid and salt) passed through the solution in the beaker to complete saturation. Ether was added in volume equal to that of the original solution, and the whole again saturated with hydrochloric acid gas. The crystalline chloride precipitated was caught on asbestos in a filter crucible, washed with a previously prepared solution of equal parts of ether and hydrochloric acid, saturated with hydrochloric acid gas, dried for half an hour at 150°–180° C., covered with a layer of pure mercury oxide, heated gently over a low flame under a ventilating hood, ignited over the blast, and weighed as the oxide. The results show that aluminum can be determined with reasonable accuracy in the presence of a pure zinc salt.

TABLE I.

	Al_2O_3 taken as the chloride. grm.	Al_2O_3 found. grm.	Error. grm.	ZnO taken. grm.	ZnO found. grm.	Error. grm.	Error corrected. grm.	Final vol. cm^3.
(1)	0·0562	0·0562	0·0000	0·1110	----	----	----	--
(2)	0·0580	0·0577	0·0003—	0·1034	----	----	----	--
(3)	----	----	----	0·1019	0·1016	0·0003—	----	--
(4)	----	----	----	0·1010	0·1007	0·0003—	----	--
(5)	----	----	----	0·1100	0·1095	0·0005—	----	--
(6)	0·0572	0·0572	0·0000	0·1014	0·1027	0·0013+	0·0007—	12
(7)	0·0563	0·0550	0·0013—	0·1026	0·1038	0·0012+	0·0008—	16
(8)	0·0577	0·0576	0·0001—	0·1000	0·1014	0·0014+	0·0006—	16
(9)	0·0559	0·0558	0·0001—	0·1020	0·1035	0·0015+	0·0005—	16
(10)	0·0563	0·0556	0·0007—	0·2024	0·2046	0·0022+	0·0002+	20
(11)	0·1111	0·1107	0·0004—	0·2092	0·2116	0·0024+	0·0004+	20

The zinc can be determined, after the evaporation of the strong acid filtrate, by any of the well known methods. It was found, however, that after thorough conversion to the nitrate by repeated evaporation with nitric acid the salt could be ignited directly to the oxide with satisfactory results. This is shown clearly in Table I, exps. (3) to (5). In experiments (3) and (4), zinc oxide was dissolved in nitric acid and the nitrate ignited again to the oxide. In experiment (5), the zinc oxide was first dissolved in hydrochloric acid and the chloride thus obtained was converted to the nitrate by evaporating the solution (5^{cm^3}) with nitric acid (2^{cm^3}), treating the residue with nitric acid (2^{cm^3}) and evaporating to dryness.

In Table I (exps. 6–11) are given the results of experiments in which both the aluminum and zinc were determined,—the former, as described, by precipitating as the hydrous chloride and weighing as the oxide, and the latter by carefully evaporating the strongly acid filtrate (best with a small current of air

playing on the surface of the liquid to avoid spattering due to the too violent evolution of the ether and gaseous acid) and finally converting the chloride through the nitrate into the oxide. It is, of course, absolutely necessary that the treatment with nitric acid shall be thorough, so that no zinc chloride may remain to volatilize when the residue is ignited. On account of the danger to platinum from the aqua regia generated by the action of nitric acid on zinc chloride, the evaporations of the filtrates from the aluminum chloride and the treatment with nitric acid were carried on in porcelain and the residual nitrate was transferred to a small crucible for ignition. In this process the porcelain was evidently attacked somewhat, so that the residual nitrate was slightly contaminated with material from the large porcelain dish. This fact accounts for the high results given in the first column of errors. However, on introducing a correction (0·0020) found by carrying through the process in blank with the quantities of reagents employed in the regular process, the results on zinc, slightly deficient, agree closely with those obtained (exps. 3–5, Table I) where the zinc nitrate was converted directly to the oxide without the previous evaporation in porcelain of a large volume of strongly acid liquid. The errors thus corrected stand in another column of the table.

These results show clearly that aluminum and zinc may be separated from one another by the action of hydrochloric acid gas in aqueous ethereal solution with a reasonable degree of accuracy.

Separation of Aluminum from Copper, Mercury and Bismuth.

The separation of aluminum from copper, mercury and bismuth does not differ materially from the separation of aluminum and zinc. Aluminum chloride is precipitated quantitatively in the presence of pure salts of these elements as shown in experiments of Table II.

TABLE II.

	Al_2O_3 taken as the chloride. grm.	Al_2O_3. found. grm.	Error. grm.	CuO taken. grm.	CuO found. grm.	Error. grm.	$HgCl_2$ taken. grm.	Bi_2O_3 taken. grm.
(1)	0·0576	0·0571	0·0005—	0·0500	----	----	----	----
(2)	0·0561	0·0557	0·0004—	0·0400	----	----	----	----
(3)	0·0570	0·0574	0·0004+	----	----	----	0·1000	----
(4)	0·0548	0·0557	0·0009+	----	----	----	0·1000	
(5)	0·0565	0·0571	0·0006+	----	----	----	----	0·1000
(6)	0·0576	0·0577	0·0001+	----	----	----	----	0·2000
(7)	----	----	----	0·0437	0·0432	0·0005—	----	----
(8)	----	----	----	0·0359	0·0359	0·0000	----	----
(9)	----	----	----	0·0345	0·0340	0·0005—	----	----
(10)	0·0558	0·0545	0·0013—	0·0319	0·0324	0·0005+	----	----
(11)	0·0538	0·0536	0·0002—	0·0343	0·0356	0·0013+	----	----
(12)	0·0566	0·0562	0·0004—	0·0337	0·0349	0·0012+	----	----
(13)	0·0577	0·0575	0·0002—	0·0651	0·0644	0·0007—	----	----

In determining the copper in the acid filtrate it was found advantageous to weigh as the oxide, but to arrive at that condition through the sulphate rather than through the nitrate (which was the transition salt in the case of zinc), as this process can be carried on safely in platinum.

In Table II (exps. 10 to 13) are given results of experiments in which the aluminum was determined as previously described by precipitation as the hydrous chloride and conversion to the oxide, the acid filtrate was evaporated in platinum and the copper determined by treating the residue with a few drops of strong sulphuric acid, heating gently to drive off the excess of sulphuric acid, and then igniting the sulphate to the oxide at a red heat. That the copper sulphate is converted to the oxide by ignition at a red heat over a Bunsen burner is shown in experiments (7) to (9) of Table II.

In conclusion the author wishes to thank Professor Gooch, under whose direction this work has been carried on, for his kind suggestions and advice.

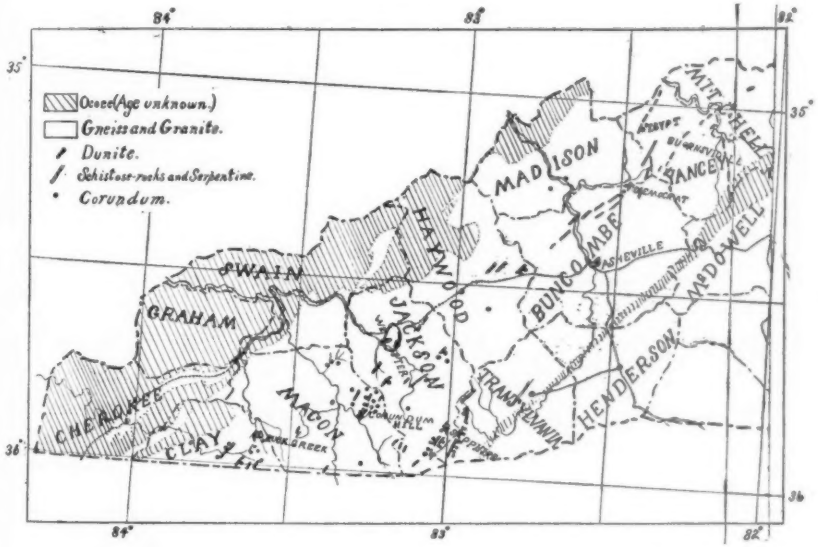
ART. V. — *On the Origin of the Corundum associated with the Peridotites in North Carolina;* by J. H. PRATT.

[Published by permission of the Director of the North Carolina Geological Survey.]

Introduction.—During the past few years there have been numerous investigations upon the character and origin of the peridotite (dunite) rocks of the Appalachian belt, especially those occurring in the southern portion of this belt. In a recent paper, J. V. Lewis* has shown that these peridotites are to be regarded as plutonic igneous rocks.

The author has examined nearly all the known outcrops of these rocks, in this State, during the past two years, in connec-

1.



tion with his work on the corundum deposits. The result of these examinations have led to the same conclusion regarding the origin of the peridotites as that held by Prof. Lewis and others. Corundum is nearly always associated with these rocks; and while several valuable contributions have been written on the occurrence and descriptions of localities, but few investigators have taken up the study of this mineral in

* Elisha Mitchell, Sci. Soc. Jour., Part II, pp. 24–37, 1895.

respect to its origin. That there are several modes of origin of corundum would seem clear from the various ways in which it occurs. Its association with the plutonic and metamorphic rocks, such as granites, gneisses and crystalline schists, is well known, as also its occurrence in basic igneous rocks. The corundum, which is the subject of this paper, is that which is found associated with the peridotites; and the accompanying map, fig. 1, shows the distribution of these and of the corundum in western North Carolina.

In the accompanying pages it is purposed to give the reasons why the corundum should be regarded as having been formed at the same time with the dunite, as having been held in solution by the molten mass of the dunite and having crystallized out among the first minerals as the mass began to cool.

2.

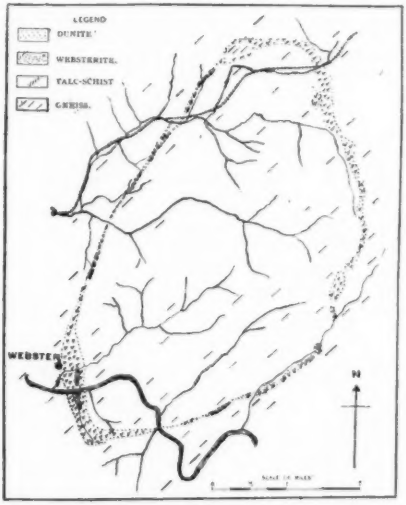


FIG. 2. Map of the Webster peridotite area. Jackson County, N. C., showing near its northern extremity a large block of gneiss entirely surrounded by the peridotites. (After Lewis.)

This theory of the origin of the corundum depends upon the igneous origin of the peridotites and it seems advisable at this point to review the reasons why the peridotites of this region are to be regarded as igneous rocks, and to state new facts bearing on this view. Most of the points brought out by Lewis have been verified by the author from personal observation, and a brief summary of them is given here:

The blunt lenticular form in which we find these peridotites

would be difficult to associate with any origin but that of an intruded igneous mass, which would also account for the apophyses that have been observed shooting off into the enclosing gneiss.

At Webster, Jackson County, as shown in fig. 2, a large block of gneiss is completely enclosed in such a manner by the peridotites, as could be attributed only to the intrusion of these in a molten condition.

The line of separation of the peridotites and the gneisses is always sharp, and there is no transitional zone from the acid gneiss to the basic peridotite. Under the microscope this latter rock shows the granular structure characteristic of plutonic origin, the grains fitting perfectly with each other without cementing material.

The stratified appearance of the olivine at Webster, Jackson County, is readily accounted for by the pronounced evidence of shearing that accompanies it. Dr. Wadsworth* has shown that the evidence given by Dr. Julian† to prove that these peridotites were of sedimentary origin could exist just as well if the rock had an entirely different origin.

At the Buck Creek and adjoining localities, amphibolite dikes cut the peridotites or pass up through the same opening with them in such a manner as to clearly indicate that the peridotites occupy areas of weakness in the gneiss, through which the dikes have found their exit most easily.

Associated with all these peridotites is chromite, which occurs in imbedded masses near the boundary of the lenticular bodies of peridotite and as disseminated particles through its borders. But at one locality, Webster, the grains of chromite appear to be disseminated throughout the mass of the dunite. The constant occurrence of this mineral, so characteristic an accessory component of the igneous peridotites, and the almost entire absence of the carbonates so commonly associated with metamorphic olivine and serpentine rocks, are strong factors in the proof of an igneous origin of these peridotites. All the carbonates that have been observed by the author in connection with the peridotites are unquestionably of a secondary origin. Five or six specimens of aragonite have been observed at Corundum Hill, Macon County, and one at Buck Creek, Clay County, intimately associated with deweylite, an alteration product of the dunite.

W. C. Kerr‡ and C. D. Smith‡, who spent much time in the study of these peridotites rocks in the field, were both of the opinion that they are of igneous origin.

* Science, iii, pp. 486, 487, 1884.
† Nat. Hist. Soc. of Boston, xxii, pp. 141–149, 1852.
‡ Report of N. C. Geol. Survey, vol. i, 1875, appendix p. 91.

Historical.—As was stated above, but little has been published regarding the origin of corundum, although many authors in their papers on the occurrence of corundum and the peridotites mention what they consider might be the probable origin of this mineral.

In 1872, C. U. Shepard* in an extended article on the corundum of North Carolina and Georgia, describes the occurrences of corundum and chrysolite, the associated minerals and what he calls the development of the "Strata" which "exhibit the following order of formations: 1. Chrysolitic rock somewhat mixed with anthophyllite; 2. a layer of micaceous rock; 3. a seam of chalcedony; 4. a stratum of chloritic rock (ripidolite); 5. the same through which the corundum is regularly diffused, sometimes in narrow veins or widening out to several feet." Nowhere in this article does he suggest the probable origin of the corundum.

J. Lawrence Smith† in describing the occurrence of corundum associated with the peridotites of North Carolina and Georgia, speaks of all the localities of corundum that he has observed or examined as exhibiting certain prominent characteristics common to all, but with each locality having its own peculiar characteristics. He says that in all cases, however, the masses of corundum give evidence of having been formed by a process of segregation, which he has described in a memoir‡ on the Asia Minor emery; that by the exercise of homogenous and chemical attractions, the minerals which constitute and are associated with emery were separated out from the calcareous rock before it consolidated.

Genth,§ although not touching directly on the origin of corundum or giving any evidence to sustain his statement, says, "that at the great period when the chromiferous-chrysolite beds were deposited, a large quantity of alumina was separated which formed beds of corundum." This corundum has subsequently been acted upon and altered and changed into various minerals; that the "veins" of chlorite, etc. are alterations of the original mass of corundum and that the corundum might be found in a less altered or wholly unaltered condition when the vein was explored below the action of surface influences. In speaking of the corundum crystals imbedded in the chlorite, Dr. Genth says the crystals "appear to have formed after a great portion of the original corundum has changed into chlorite, as if there had been an excess of alumina ready for combination, which, not finding a supply of

* This Journal, III, iv, pp. 109–114, 175–177, 1872.
† This Journal, III, vi, pp. 180–6, 1873.
‡ This Journal, II, x, p. 354, 1850.
§ Proc. Am. Phil. Soc., xiii, pp. 361–406, 1873, and this Journal, III, vi, pp. 461–462, 1873 (review).

the requisite amount of silicic acid and bases, had again crystallized as corundum."

In an article on corundum and its associated rocks, C. D. Smith* points out the facts that led to his belief in the igneous origin of the peridotites, but does not discuss the same. He calls attention to the occurrence of corundum chiefly in chlorite veins and says "the chlorite seems to have been first crystallized, and then, the alumina of which the corundum is composed was evidently in a state of solution and must have permeated the chlorite either in thermal waters or steam." The only points given to sustain this theory are that plates or scales are sometimes enclosed in the corundum and that corundum has been observed that conforms in its faces and general shapes to the chlorite that is present. The other points bearing on the origin of the corundum that he undoubtedly had in mind he makes no mention of in his article. Dr. Smith also states that he found "chrysolite attached as an enveloping matter to considerable masses of corundum." He makes, however, apparently no further mention of this occurrence in any of his writings.

In a description of the "Jenks Corundum Mine," Dr. R. W. Raymond† calls attention to the occurrence of transparent nodules of corundum in a matrix of the same mineral, and also of the great variation in the appearance of the corundum from the different veins. One of the veins has produced more of the gem material, while it contains but few large masses of the corundum.

Julian, in his paper already cited, considered the corundum in all cases a secondary or alteration product, and explains all the phenomena of alteration in the veins by the introduction of a solution of soda and alumina into the fissures, during the period of alteration and metamorphism, believing at the time that the dunite was of sedimentary origin.

In an article commenting on Julian's‡ theory regarding the origin of the peridotites referred to above, Wadsworth.§ in speaking of the corundum, says that the corundum is looked upon as a secondary mineral, and not as Genth held, the primary material from which many minerals originated.

Chatard‖ made a very careful chemical study of the material collected across the contact between the gneiss and dunite at Corundum Hill. He points out as a result of his chemical analyses, that starting from the gneiss there is a progressive

* Report of N. C. Geol. Survey, vol. i, p. 91, 1875.
† Trans Am. Inst. of Min. Engrs., vol. vii, p. 89, 1879.
‡ Nat. Hist. Soc. Bost., xxii, 141–149, 1882.
§ Science, iii, 1884, p. 486.
‖ U. S. Geol. Survey, Bulletin 42, pp. 45–63.

increase of magnesia in the vein material as the dunite is approached, and that there is an approximate decrease in the percentage of alumina.

From these analyses, the series from the section across the vein are divided into three groups, aluminum silicates, aluminum-magnesium silicates, and magnesium silicates. The middle term of this chemical series is also the middle number of the field series. He regards the corundum as an accessory mineral, frequently not being found at all in the vein, and sometimes but in small amount, and therefore to be considered as the result of a certain balance between the magnesium and aluminum silicates, which have by their union produced the chlorite and vermiculites.

In describing the occurrence of corundum at Chester County, Pa., Mr. J. P. Lesley* says that it seems difficult to imagine its excessive compact hardness as produced in any other way than by heat.

J. V. Lewis'† report on "Corundum and the Basic Magnesian Rock in North Carolina" is mainly a report of field observations and does not take up any discussion of facts bearing on the origin of the corundum; though many points of interest and importance are brought out regarding the alterations of the dunite and of the character of the vein and vein materials and also concerning the alteration of corundum.

The corundum deposits of Georgia are similar, almost identical, with those in North Carolina. F. P. King,‡ in his report on the corundum deposits of Georgia, which is principally devoted to the description of localities, occurrences and varieties of corundum, etc. comes to the conclusion that corundum is an accessory mineral and that its presence is occasioned by an excess of alumina present in the rock masses, "chrysolite, gneiss and hornblende gneiss." This is explained by the alteration of these rocks into magnesium silicates, alkaline salts and ferro-silicates, which in conjunction with carbonic acid of percolating waters would dissolve the combined alumina, and produce on crystallization all the minerals associated with corundum; and when the alumina is in excess this would produce corundum itself.

As has been shown above, a number of theories concerning the origin of the corundum have been advanced. With one exception, however, they are all prior to the numerous and elaborate experiments that have been made by different investigators on the solubility of alumina in a molten basic glass and the separating out of corundum and spinel crystals from

* Penn. Geol. Survey, C4, p. 352, 1883.
† N. C. Geol. Survey, Bulletin No. 11.
‡ Georgia Geol. Survey, Bulletin 2.

this on cooling. They are also prior to Vogt's* very important investigations into the igneous origin of certain ore deposits. All these experiments have aided very materially in solving the numerous problems in relation to the origin of many of the ores; and in the present investigation the facts proved by these experiments have been of exceptional assistance in the compiling of evidence to substantiate the theory proposed.

Evidence bearing on origin of Corundum.—In all the field observations a careful search was made to find the corundum directly in contact with the dunite, and this was observed at one locality. At the Egypt mine, on the western slopes of the Samson mountains, about ten miles west of Burnsville, in Yancey county, several specimens have been found with the corundum crystals entirely surrounded by granular dunite, and showing none of the chloritic minerals usually present with the corundum (fig. 3). Both the dunite and the corundum

3.

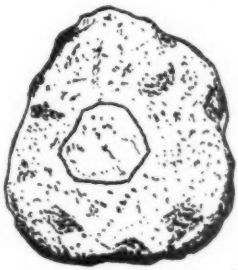


FIG 3.—Corundum crystal in altered dunite. From Egypt, Yancey County. One-half natural size. (Drawn from a photograph.)

have altered somewhat, the corundum having a little muscovite developed on its basal termination, while the dunite is stained a yellowish brown and is rather friable. The specimens that were examined were collected by Mr. U. S. Hays, who was prospecting in the vicinity of the mine, and were loaned to the author by J. V. Lewis,† who has described this occurrence. There was no mining being done when this locality was visited by the author, but miners living in the vicinity, and who have worked in the mine, report the finding of many fragments of corundum in the dunite similar to the one here figured.

Although this is the only locality where the corundum has

* Zeitschr. für Prakt. Geol., Nos. 1, 4 and 7, 1893.
† N. C. Geol. Survey, Bulletin No. 11, p. 60.

been found directly in dunite, it has been observed in serpentine, which is the commonest alteration product of dunite. At the Cullakeenee mine, Buck Creek, Clay County, corundum was found that was bordered with serpentine. Some of the specimens observed show the small particles of corundum either entirely or partially surrounded by serpentine and the whole mass of corundum and serpentine surrounded by clinochlore. In another specimen a streak of corundum about an inch wide lies between two zones of serpentine, from a quarter to three quarters of an inch wide, and these in turn are bordered by a talcose and enstatite rock (fig. 4).

4.

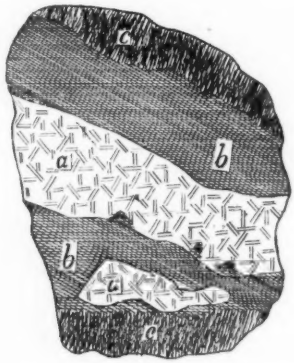


FIG. 4. Drawn from hand specimen. One-half natural size: *a*, corundum with a little margarite developed in a few places near the border of the serpentine *b*. The serpentine blends somewhat with the talcose rock *c*, which on its outer surfaces is composed of enstatite.

Crystallized corundum has been observed, where the crystals, one end of which merge into the massive corundum, project out beyond the mass, and these projecting portions are often partly or entirely surrounded by chlorite; while in other cases separate corundum crystals are imbedded in the chlorite. The best crystals of corundum have been found at Corundum Hill, where they occur in the conditions just mentioned.

Many of the crystals, especially those free from alteration and decomposition, or those only slightly altered, are usually well developed, with smooth even faces and sharp edges.

In a number of the mines, corundum is found in contact with and surrounded by spinel. At the Carter Mine, near Democrat, Buncombe County, the corundum is found in masses of a white and pink color, intergrown with a greenish

black massive spinel. In thin splinters the spinel is of a very handsome emerald-green color. The masses of the corundum and spinel are partially surrounded by a deep green chlorite; which latter has also in places been developed in small greenish scales, between the corundum and spinel; though the contact of the spinel and of the corundum is usually sharp and distinct, showing no sign of alteration. The presence of minute scales of greenish chlorite occur still more rarely in the corundum and spinel near the junction of these minerals with the external mass of the chlorite. All the massive corundum shows the characteristic parting lines; and the spinel shows distinctly the conchoidal fracture.

A massive, coarsely to finely granular spinel is found at the Corundum Hill mine, Macon County, which has disseminated through it small grains and fragments of pink and white corundum. The spinel and corundum are closely associated with chlorite, which is here more generally developed between the corundum and spinel and in the spinel (between the granules) than it was at the Carter mine. The spinel in the mass appears black, but in small splinters it shows a green color.

The corundum is found in the dunite in two different relations, one in the zone of alteration products developed at the contact of the dunite and the gneiss, and the other in a similar zone of alteration products, but which are bounded on both sides by the dunite. For convenience, the occurrence of the corundum in these alteration products between the dunite and the gneiss will be designated as a contact-vein and the other as a dunite-vein. The bounding walls of a dunite-vein are not necessarily of dunite; but may be of serpentine, the common alteration product of this mineral.

Where the corundum is found in the contact-vein, the following sequence is usually observed in a cross-section extending from the gneiss to the unaltered dunite:

a. Gneiss, hornblendic or micaceous, apparently unaltered.
b. Gneiss with same general appearance as *a*, but so decayed that the particles readily separate from each other.
c. Yellowish vermiculites, varying considerably in thickness, with a maximum of 6 or 8 inches, and in places entirely absent, so that *b* comes directly in contact with *d*. Where present, *c* often merges into *d*.
d. Green chlorite, varying in thickness much like *c*, and absent entirely in places.
e. Chlorite and corundum. Sometimes with a little vermiculite. In places this mass may be largely of corundum, and it is what is called the "corundum vein," varying in thickness from a few inches to 12 or 15 feet.

f. Green chlorite. As far as observed, always present, and varying from 1 to 12 inches in width.

g. Enstatite; in places hard and compact, several feet wide; in other places only a few inches wide, usually merging into *h*.

h. Talcose rock, usually fibrous, varying from a few inches to several feet in thickness.

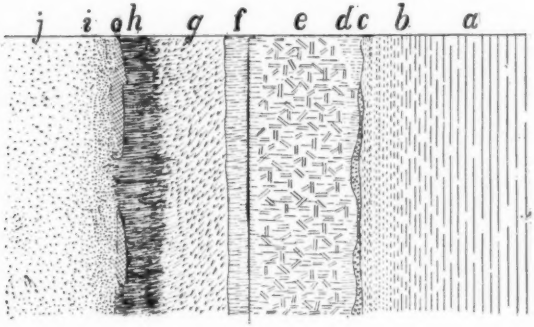
i. Dunite, more or less altered, friable and stained with ferric oxide.

j. Dunite, apparently unaltered, quite extensive.

Between *h* and *i* a seam of yellowish clay is sometimes observed which often contains a narrow seam or fragments of chalcedony.

From what could be learned from actual observations and inquiry among the miners, *c* and *d* are sometimes absent, and when this is the case, *e*, a mixture of chlorite, vermiculite and corundum, is seemingly in direct contact with *b*. The chlorite, however, on the dunite side of the section is constant. The thickness of the several zones (*a*, *b*, *c*, etc.) in such sections varies greatly at different places; and the distance across such sections may be said to vary at different points, even in the same region, from a few feet to 30 or 40 feet. The accompanying diagram (fig. 5) represents the cross section of a contact vein observed at Corundum Hill.

5.



In the diagram, fig. 5, *a* represents gneiss, apparently fresh and unaltered, passing into *b*, which has somewhat the appearance of the unaltered gneiss, but is so decayed that the particles readily separate from each other; *c*, narrow zone of vermiculites that sometimes is entirely lacking; *d*, green chlorite, clinochlore, partially decomposed and forming the vermiculites of *c*; *e*, the corundum-bearing zone, a mass of the green chlorite with crystals and fragments of corundum dis-

seminated through it; *f*, another zone of the green chlorite; *g*, mass of interlocking bladed grayish crystals of enstatite that merge into *h*, a fibrose talcose rock which passes into *i*, an altered dunite that is somewhat friable and stained with ferric oxide; *j*, hard and apparently unaltered dunite. Between *h* and *i* a mass of soft, yellowish clay, *o*, containing fragments of chalcedony.

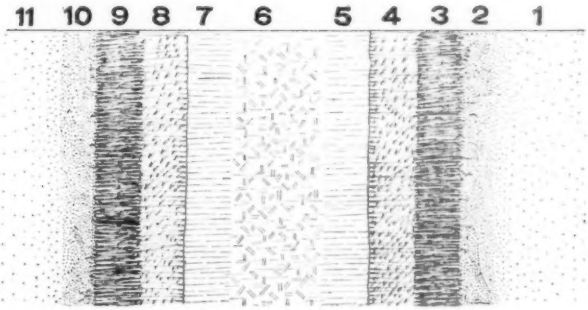
The line of contact between the zone of alteration products and the gneiss was very sharp and distinct in all the contact-veins examined. The minerals developed between the corundum-bearing zone and the dunite are of great abundance and different from those between this zone and the gneiss.

In a cross-section of a dunite-vein at a shaft near the southern part of Corundum Hill, in a distance of from 20 to 25 feet, the following has been observed:

1. Dunite, hard and apparently unaltered.
2. Dunite, somewhat friable and discolored, passing into 3.
3. Talcose rock, fibrous, merging into 4.
4. Enstatite, grayish and somewhat fibrous.
5. Green chlorite, 6 to 15 inches in width.
6. Green chlorite, corundum and spinel, 6 to 8 feet wide.
7. Chlorite (same as 5).
8. Enstatite (same as 4).
9. Talcose rock (same as 3).
10. Dunite (same as 2).
11. Dunite (same as 1).

The similarity of the two parts of the vein, each side of the corundum zone, as described above and illustrated in fig. 6, is very apparent.

6



In fig. 6, 1 and 11 represent the apparently unaltered dunite; 2 and 10, dunite somewhat friable and stained and passing into 3 and 9, a fibrous talcose rock, often carrying a green

actinolite and some green chlorite; 4 and 8, a grayish, rather fibrous, enstatite rock that merges into 3 and 9; 5 and 7, green chlorite passing into 6, a mass of chlorite, corundum and spinel.

Although the section just described represents a particular one, it was observed that in all of the dunite veins, the character of the vein was the same on each side of the corundum-bearing zone. As has been stated already, either a talcose or serpentine rock may be the limit of the cross section. In one of the dunite veins at Corundum Hill, near the west end of the outcrop, the zone of corundum, chlorite and vermiculites is in direct contact with a serpentine rock both on the hanging and foot wall. This zone is divided, and in one place almost pinched out by a mass of serpentine rock.

The appearance and character of the veins vary according as they are contact-veins or dunite-veins. In a dunite-vein the approximate trend of the vein is towards the center of the mass of dunite. As these veins penetrate the dunite mass they usually grow less and less in width until they pinch out. This is especially a prominent feature at Buck Creek, Clay County, N. C., and at Laurel Creek, Rabun County, Ga.

In a contact-vein, however, the corundum seems to extend downward indefinitely along the line of contact. Supplementary-veins are often encountered branching off from a contact-vein, toward the center of the dunite, and these, like the true dunite-veins, grow less and less in width until they pinch out entirely. This variation in the occurrence of the corundum in the different veins has been observed by many of those who have prospected for and mined corundum in this region.

Discussion of the Problem.—The theory advanced by the author, as given in the introduction, is that the corundum was held in solution in the molten mass of the dunite when it was intruded into the country rock and that it separated out among the first minerals, as the mass began to cool.

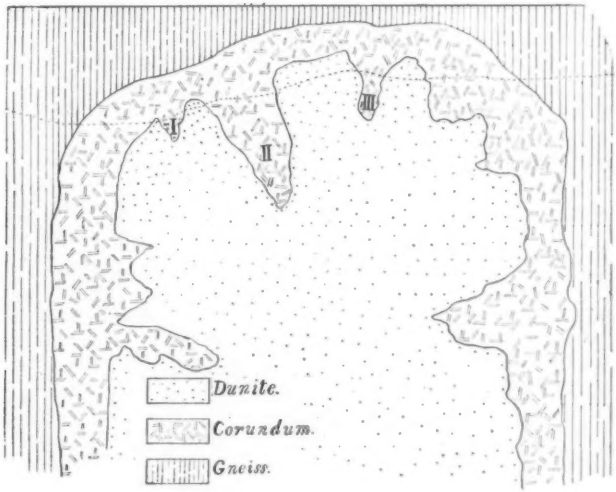
The dunite magma holding in solution the chemical elements of the different minerals would be like a saturated liquid and as it began to cool the minerals would crystallize out, not according to their infusibility but according to their solubility in the molten magma. The more basic portions, according to the general law of cooling and crystallizing magmas, being the most insoluble, would therefore be the first to separate out. These would be the oxides containing no silica, which in the present case would be alumina and chrome spinel and the corundum.

Morozewicz* has shown by some very important experi-

* Zeitschr. für Kryst., vol. xxiv, p. 281, 1895.

ments that molten glass of a character similar to the basic magnesian rocks would dissolve alumina readily, and as this molten mass began to cool corundum and spinel were the first minerals to separate out. According to this, the corundum and spinel would be the first to crystallize or solidify out from the molten mass of the dunite as this began to cool, and this would take place first on the outer border of the mass, because here it would cool first. Convection currents would then tend to bring a new supply of material carrying alumina into this outer zone, and when this zone was reached, crystallization would take place and the alumina would be deposited as corundum.

7.



This is essentially the idea advanced by Becker* in a paper on "Fractional Crystallization of Rocks," and where this process has taken place in dikes and laccolites, a concentration is observed of the earlier and more basic minerals at their outer boundary.

The more basic the magma the more fluid it is apt to be, and the more tendency there is for this process to take place, as shown by many well known instances which have been described by different geologists.

Figure 7 represents the author's idea of the appearance of a vertical cross-section of a mass of dunite, that held corundum

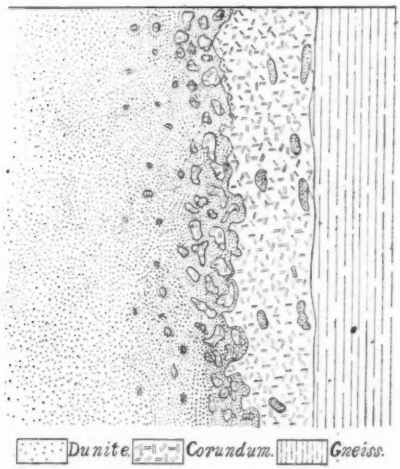
* This Journal, vol. iv, 1897, p. 259.

in solution, soon after its intrusion into a gneiss. In this figure the corundum zone has been greatly exaggerated in order to better illustrate the cross-section. The corundum would be concentrated toward the borders of the dunite and would make a sharp and nearly regular contact with the gneiss. With the dunite, however, the contact would sometimes be sharp and regular, while at others there would be an irregular line of contact and masses of the corundum would penetrate into the dunite.

The rapid erosion to which the rocks in this mountain region have been subjected would readily wear them down to their present condition, represented by the dotted lines in fig. 7.

The dunite-veins, I, II, and III in fig. 7, which at the present time have no connection with each other but are each separate and distinct, were at the time of their formation part of the corundum concentrated along the border of the dunite. Some of these veins would soon be worked out, while others might be explored for a hundred feet or more without any apparent change in their width.

8



This explanation will account for all the variations in the occurrence of the corundum in the different veins.

The corundum crystallizing out from the molten dunite, which would be a very basic magma, would be concentrated toward the margins and where in many cases there would be a sharp separation (at the time of formation) between the corun-

dum and the dunite, in others there would be a somewhat gradual passage from the corundum to the pure dunite, as illustrated in fig. 8.

The pressure and the temperature and other physical conditions would affect the crystallizing and the separating out of the minerals from the molten mass, and this will explain the great variations observed in the corundum found in the same mass of dunite. Thus, at Corundum Hill there occur masses of block corundum, large rough crystals, small well-developed crystals, and particles or grains of corundum.

The differentiation of the basic dunite magma upon cooling is similar to what Vogt* and Adams† have described concerning the separation of sulphide deposits from a molten gabbro magma. The segregation or concentration of these ores is usually near the contact of the gabbro with the gneiss and is always sharply separated from the gneiss. While there is sometimes a distinct line of separation between the ore and the gabbro, at others there is a gradual transition from the ore to the pure gabbro. It might be expected that the corundum would be found surrounded by the dunite, but as was stated on page 55, there is but one locality known to the author where the corundum is found directly in the dunite. The absence of any general occurrence of the corundum in dunite is readily explained by the ease with which the dunite itself suffers decomposition.

The corundum concentrated in the dunite near the contact with the gneiss, where the thermal waters coming in contact with the heated masses would have the best chance to act, would furnish alumina for reacting with the dunite to form the aluminum-magnesium silicates found surrounding the corundum. That the dunite decomposes very readily is apparent from the numerous specimens found of the dunite completely surrounded by foreign material that must have been formed at its expense. The corundum has been found in the serpentine but this is often surrounded by chlorite.

The descriptions of the cross sections of the corundum veins given on pages 57–60 are similar to those described by Shepard‡, Chatard§ and Lewis‖, and show practically the same sequence.

As the dunite and corundum began to alter and decompose by the action of atmospheric agencies and thermal solutions, there would be formed a series of decomposition minerals on

* Zeitschr. für Prak. Geol., Nos. 1, 4 and 7, 1893.

† On the Igneous Origin of certain Ore Deposits; read before the Gen. Min. Asso. of the Prov. of Quebec, Montreal, Jan. 12, 1894.

‡ This Journal, III, iv, p. 111, 1872.

§ U. S. Geol. Survey, Bulletin 42, p. 49, 1887.

‖ N. C. Geol. Survey, Bulletin 11, p. 93, 1896.

the dunite side of the vein and but a few on the gneiss side. The decomposed material that would be found on the gneiss side of the vein would vary according to the amount of the dunite that had been held between the corundum and the gneiss (fig. 8). The common decomposition product surrounding the corundum is the chlorite (clinochlore) or a further alteration of the mineral to the vermiculites.

Between the corundum imbedded in the chlorite and the gneiss there is often but very little and at times no chlorite or vermiculites developed, the corundum-bearing portion of the zone being apparently in direct contact with the gneiss (*b* of cross-section, p. 58).

In the dunite veins the alteration products developed are the same on both sides of the corundum-bearing zone and are in most cases nearly an exact reproduction of the dunite side of a cross section of a contact-vein (figs. 5 and 6). This demonstrates that the gneiss had no influence in the formation of the alteration products of the contact-veins.

The analyses of Chatard* which show the chemical character of the vein to increase in magnesia and decrease in alumina as the dunite is approached, are in accord with the present theory regarding the formation of the alteration products.

The penetration of molten material carrying corundum into the gneiss during the differentiation of the molten dunite, would explain the occurrence of any corundum found in the gneiss bordering a contact vein. There is a similar occurrence of the sulphides penetrating into the gneiss during the cooling and differentiation of a molten gabbro, which is well illustrated in Vogt's* article and have been reproduced by Adams.†

Pirsson's‡ theory regarding the origin of the Montana sapphires, occurring in a basic igneous dike,§ is that these crystals separated out from the molten magma as this began to cool. He points out that originally the rock could not have been sufficiently rich in alumina to have allowed a general separation out of that material, and undoubtedly the magma took up quantities of inclusions from the sediments through which it passed. Clay shales, or a rock of similar composition, must have been among these sediments; and the fragments of this shale would be dissolved by the basic magma from which on cooling the alumina would separate out as corundum.

Summary.—This theory of the igneous origin of the corundum associated with the peridotites is in accord with the field

* U. S. Geol. Survey, Bulletin 42, pp. 50–56.
† Already cited.
‡ This Journal IV, iv, p. 422, 1897.
§ This Journal III, l, p. 467, 1895.

observations, the most important of which are the occurrence of the corundum surrounded by granular dunite and also by serpentine; its occurrence with and surrounded by spinel; the sharp contact between the gneiss and the alteration products of the contact-vein; the same sequence of alteration products which are found on both sides of the corundum-bearing zone of a dunite-vein and which are almost identical with the dunite side of a contact-vein; the usual narrowing and pinching out of the dunite-veins, the trend of which is toward the center of the mass of dunite; while the contact-vein seems to extend downward indefinitely.

The laboratory experiments of Morozewicz* and Logorio† into the solubility of alumina in a molten basic glass and the separating out of the corundum and spinel as the first minerals when the glass began to cool, also give strong support to the igneous theory of the origin of the corundum accepted by the author.

Thus the facts obtained in the field and in the laboratory both point to the same conclusion regarding the origin of the corundum associated with the peridotite rocks.

In conclusion the author desires to express his thanks and indebtedness to Prof. L. V. Pirsson of the Sheffield Scientific School for valuable aid in the preparation of this paper.

N. C. Geological Survey, March, 1898.

* Cited on p. 60.
† Zeitschr. für Kryst., vol. xxiv, p. 285, 1895.

ART. VI.—*Erionite, a new Zeolite;* by ARTHUR S. EAKLE.

THE mineral described in the present paper occurs in a rhyolite-tuff from Durkee, Oregon, and was discovered and presented to the museum for identification by Mr. E. Porter Emerson. The tuff consists of a dull gray, amorphous groundmass containing numerous patches of light brown, pitchstone-like material, fresh sanidine and plagioclase crystals, with an occasional dark silicate altered to chlorite. Large masses of opal fill the cavities. This opal is mostly of the milky and hyalitic kinds, yet often grades into a beautiful precious variety, showing a rich play of colors and forming excellent gem material.

The zeolite occurs as very fine threads, having a snow-white color and pearly luster. These threads resemble fine woolly hairs, having the same curly nature and soft feel. They occur, sometimes as white tufts firmly adhering to a solid base of milky opal, resembling a filamentous growth of the opal, and sometimes as compactly matted fibers filling the rock fissures. In some of the specimens, the filaments are encrusted with a thin shell of white opal, indicating that the opal was subsequently formed from the zeolite.

The mineral fuses easily and quietly in the Bunsen flame, to a clear colorless glass. Heated in a closed tube, the fibers darken slightly, emit a burnt odor, and give off much water which reacts strongly alkaline. The tuff also shows this alkaline reaction, so it is evident that organic matter of some sort is present in the rock. The organic substance in the zeolite must be a part of its constitution and not a contamination of any hydroscopic water, since it cannot be eliminated by long boiling in water or acids.

The weight of the fibers fluctuates materially from the influence of the air, making correct weighings difficult. The loss over sulphuric acid is water of crystallization, as evidenced by the rapidity with which such loss is regained on exposure. Two-thirds of a gram of the material which had been exposed to the air of the laboratory for two months, was weighed in a platinum crucible and placed in a desiccator for a week. At the end of this period the loss was 6·95 per cent; in one hour, on the balance pan, one-half of this loss was regained; in two and a half hours, the fibers reached their original weight; in four hours, their weight became stationary and exceeded the original weight by 60 milligrams, although the weighings were made in a warm dry room and the balance case contained a beaker of strong sulphuric acid. In the air bath at 110° C.,

the loss was 7·68 per cent; at 200° C. it amounted to 13·32 per cent; at 280° C. it was 15·25 per cent, of which last all but 2 per cent was regained over night, when placed under a beaker in the laboratory. The loss was practically constant for the different temperatures, as shown by repeated trials and different durations of heating. All water of crystallization was apparently expelled at 280° C., for on further heating up to 400° C. no more loss was experienced. The remaining water was expelled at low red heat, without fusion, the total loss averaging 17·30 per cent. This makes a difference of about 2 per cent as probably constitutional water. Alkaline water was still given off at 200° C., but at 280° C. all evidence of ammonia had disappeared. The water of crystallization evidently contains the organic substance, and considering the ease with which the fibers absorb moisture, it is readily conceivable that such moisture may have carried a certain amount of organic impurity into the mineral. The amount of ammonia was determined by combustion with soda-lime, collecting the gas in standardized H_2SO_4 and titrating with KOH solution, the result being 0·22 per cent. While this amount is too small to affect the general formula of the silicate, even if considered an essential constituent, it is nevertheless sufficient to form an important pyrognostic characteristic. The fibers are soluble with extreme difficulty in HCl. Complete decomposition was effected by boiling them in concentrated acid, evaporating the solution to dryness, grinding the residue and again boiling, the silica in the end separating as a fine sand, with no gelatinization. In the analyses, decomposition was effected (1) by fusing the fibers with the mixed carbonates, (2) by first igniting to a glass and then fusing with the carbonates, and (3) by dissolving in HCl. These various analyses were sufficient to establish the molecular ratio of the mineral, although from the nature of the material, closely agreeing duplicates were difficult to obtain. An average of the analyses gave

		Ratio.	Calculated for $6SiO_2 . Al_2O_3(Ca_1K_2Na_2)O + 6H_2O$
SiO_2	57·16 = ·953	6·03	56·52
Al_2O_3	16·08 = ·158	1·	16·01
CaO	3·50 = ·062	1	4·40
MgO	0·66 = ·017		
K_2O	3·51 = ·039		3·69
Na_2O	2·47 = ·040		2·43
H_2O	17·30 = ·960	6·07	16·95
Total	100·68		100·00

Here the ratio $Si : Al_2 = 6 : 1$, $Si : H_2 = 1 : 1$, $R : Al_2 = 1 : 1$,

while $Ca+Mg:K_2:Na_2 = 2:1:1$. This gives a general formula $6SiO_2$, $Al_2O_3(CaK_2Na_2)O+6H_2O$, or allowing one molecule of water as hydroxyl, $H_2Si_6Al_2CaK_2Na_2O_{17}+5H_2O$. The general formula is analogous to that of stilbite, in which the calcium has been largely replaced by the alkalies, but in other respects the zeolite has no resemblance to stilbite and is undoubtedly a distinct mineral. The specific gravity is 1·997, determined by the methylene iodide and Thoulet solutions. Unfortunately the filaments are so delicate that complete optical determinations cannot be made. The mineral has a moderately strong double refraction. The acute bisectrix lies parallel to the fibers, since an axial figure normal to the obtuse bisectrix can be seen in the fibers. The axis of least elasticity is apparently in the direction of the fibers, making the mineral positive in character. Extinction is exactly parallel and indicates an orthorhombic crystallization. Several attempts were made to get a cross section of a bunch of the fibers, by imbedding them in various media, but nothing in the way of an axial figure was obtained. No difference was observed in the polarization colors between the fibers heated to 280° C. and those not heated.

The name *erionite*, from ἔριον, wool, is proposed for the zeolite, on account of its woolly appearance.

An analysis of the milky opal associated with the mineral gave SiO_2 95·56, H_2O 4·14 per cent and a trace of alumina.

Mineralogical Laboratory, Harvard University, April, 1898.

ART. VII. — *The Winter Condition of the Reserve Food Substances in the Stems of certain Deciduous Trees;* by E. MEAD WILCOX.

THE investigations, of which this is a preliminary account, were undertaken to determine more definitely some of the essential physiological processes involved in the dormant periods of our woody plants. Stated briefly the problem was (*a*) to determine what are the conditions in which the reserve food substances are stored in the twigs during these dormant periods, i. e. during the winter, and (*b*) what if any changes they undergo during this period, and (*c*) how do these changes affect the renewal of activity by the buds at the beginning of the subsequent season of growth.

And it is to be noticed that the phenomenon of the renewal of activity by buds is not essentially unlike the process of the germination of seeds—in fact both phenomena may well be classed under the one head of the germination of dormant organs.

It is well known that this periodic alternation in the vegetative growth of the tree of a period of growth and a period of rest is so regulated that both normally occur at definite seasons of the year. And this fact has led many writers to ascribe this periodicity to the effects of temperature and in general to external rather than to internal changes. However, these dormant periods often occur under the most favorable conditions both as to moisture and temperature, while germination and the renewal of vegetative activity quite as often occur under rather adverse external conditions. In fact more careful study tends to show that the apparently close dependence existing between vegetative rest and unfavorable external conditions is due to the fact that in the cells there are taking place certain remarkable changes that require for their completion a dormant period. This fact was definitely determined for the potato tuber by Müller-Thurgau '82, '85.

The two very interesting papers by Müller-Thurgau give the chemical changes that occur in the potato during its dormant period. In fact his work shows certainly a dependence of the renewed growth of the tuber upon the completion of these changes in the starch and other reserve food material stored within the tuber. Hartig, '58, expressed the view that the starch is stored in the cells of the bark and wood during the summer and that it remains there unaltered in position or amount till it is entirely or partially consumed in the production of new organs the following

spring. This has been the accepted view until within very recent times. Gris '66 and '66*a* also shared in this view and says ('66, page 443): "Qu'il n'y a que deux grandes mouvements des matières nutritives à l'interieur du tronc des arbres: la gênese de ces matières en ètè, et leur résorption au printemps." Famintzin and Borodin, '67, noted in their study of a birch (the species is not given) that there was a rapid formation of starch in the spring in the cells of the male catkin and in the young twigs in both of which there had been no starch during the winter. They suggest that this starch might have been formed from the oil that was stored in abundance in the same regions and that gradually disappeared during the period of starch formation.

Schroeder, '69, in his paper on *Acer platinoides* came to much the same conclusion, so far as concerns starch, as did Gris. Grebnitzky, '84, studied eighteen species of trees for a period of two years but came to quite different conclusions than either of the others mentioned above. He says (l. c., page 157): "Die Stärke wird im Herbst audgespeichert, bleibt jedoch während des Winters nicht als solches erhalten, indem sie wahrscheinlich in Fett übergeht, in Frühlinge erscheint sie vor dem Knospenbruche wieder." By this we see that Grebnitzky recognized two periods of starch maximum alternate with two periods of starch minimum in the twigs. He says further that in all the soft-wood trees, as the Linden, all the starch disappears in winter while in the hardwood trees that the starch in the bark only is replaced.

Baranetzky, '84, held that this change of starch into oil is a process that takes place only in the presence of active protoplasm and that it goes on faster at higher temperatures than at lower temperatures. And this last assumption seemed to him to explain the fact that the transformation of starch into oil does not take place in roots at all or at least not to such an extent as in stems and all parts above ground. This seems to me to be a mere assumption that does not adequately explain the conditions he considers to exist. Russow, '84, carried on some experimental work in several species of trees. He records a gradual reduction in the amount of starch in the bark and considers that it was replaced by oil. He thought that the amount of starch in the woody part of the stems remained the same during the winter. He further says that the starch reappeared in the bark in the course of a week in the spring.

Fischer, '88 and '90, comes to the conclusion that there exists an autumn and a spring maximum period as to the amount of starch in the twigs. He divides the species that he examined into two classes distinguished by the starch in one case changing into oil and in the other into glucose. For further details

the reader is referred to the original paper as it is too lengthy to review properly in full in this preliminary paper

My studies during the past year have been largely confined to the question of starch formation and distribution and its relation to the growth of the tree. And in this preliminary communication I purpose giving some of the results so far obtained that throw light upon this particular subject.

The following list includes the names of the species which I have studied: *Gordonia altamaha*, *Æsculus flava*, *Æsculus flava purpurascens*, *Æsculus glabra*, *Æsculus lyoni*, *Sassafras officinale*, *Asimina triloba*, *Celtis occidentalis*, *Ailanthus glandulosus*, *Syringa vulgaris*, *Magnolia umbrella*, *Magnolia conspicua* (hybrid), *Acer saccharinum*, *Diospyros virginiana*, *Euonymus atropurpureus*, *Cratægus tomentosa*, *Cornus florida*, *Fagus ferruginea*, *Pyrus malus*, *Rhododendron maximum*, *Rhododendron punctatum*, *Cladrastris tinctoria*, *Lindera benzoin*, *Liriodendron tulipifera*, and *Hamamelis virginiana*. In addition to the above twenty-five species a number of others have been examined from time to time.

I have collected material* from each of the above species at intervals of one or two weeks since the first of October, 1897. Buds and sections of the stem were collected each time and preserved in the same bottle for further study. A variety of fixing reagents have been employed but none gave so good results as the following two: (1) a saturated solution of picric acid and corrosive sublimate in 95 per cent alcohol and (2) a saturated solution of corrosive sublimate in 95 per cent alcohol. In the former case washing out was accomplished with weak alcohol and in the latter case the sublimate was removed with water. All the material after thorough washing was placed in 50 per cent alcohol for preservation or imbedding. It was found desirable in the study of protoplasmic connections to fix the material in the osmic-acid-uranium-acetate mixture first recommended by Kolossow† and employed by Gardiner‡ for this purpose.

Imbedding was accomplished either in a soap mixture or in paraffine. For the details of the former method the reader is referred to my recent paper§ on that subject. By the use of the following paraffine method I was able to obtain perfect serial sections of buds as thin as $6\frac{3}{4}$ or 10^{mm}. The buds are thoroughly dehydrated in absolute alcohol and then an equal volume of chloroform is added to the alcohol and the material

* My thanks are due Mr. J. G. Jack of the Arnold Arboretum for assistance in the collecting of material.

† Zeit f. wiss. Mik., v, 50–53, 1888.

‡ Proc. of the Royal Society, lxii, 100–112, 1897.

§ Journ. of Applied Mic., i, 68–69, 1898.

is to remain in this mixture for about six hours or more. It is then placed in pure chloroform for about the same time; at the end of which time it is transferred to a solution of paraffine in chloroform and allowed to remain for about a week in this solution. Complete infiltration in the melted paraffine can now be secured in half an hour to an hour. By this method beautiful ribbon sections are easily cut on the Minot-Zimmermann microtome. These ribbons are fastened to the slide by the usual albumen fixative.

Staining was accomplished by one of the following methods—the particular method depending upon the character of the cell contents to which I desired to give special attention. In the study of the leucoplastids and proteids crystalloids one of the methods given by Zimmermann* was followed. His acid-fuchsin "method B" is well adopted to staining single sections while for staining on the slide the method of Altman is better. Mann's methyl-blue-eosin method was found serviceable in the study of proteid crystalloids as well as for general cytological purposes. This method was employed by Lily H. Huie† in the study of proteid crystalloids, and as the article appears in a periodical that is not everywhere accessible I will give the details of the method here. Two solutions are first made as follows:

A. 1 per cent solution of methyl-blue in water	35cc
1 per cent solution of eosin in water	45cc
Water	100cc

B. 1 per cent solution of NaOH in absolute alcohol.

Sections are to be stained for twenty-four hours in A and then rinsed in water and dehydrated up to absolute alcohol. The sections are now placed for a few minutes in thirty cubic centimeters of absolute alcohol to which a few drops of B has been added. The NaOH is then removed from the sections with absolute alcohol and they are then rinsed for one minute in water. Red clouds are here given off and the sections become blue again. They are now placed in water slightly acidulated with acetic acid to deepen and restore the blue color and to fix the eosin in them. They are now dehydrated, cleared with xylol and mounted in balsam. In the special study of the protoplasmic connections several stains were employed but these methods will not be given here.

Before proceeding to the discussion of the results so far obtained and their bearing on the general subject of the dormant periods of plants, I will give in some detail the facts observed in the study of two species, *Liriodendron tulipifera* and *Pyrus malus*.

* Microtechnique (Trans.), p. 195–198, 1893.
† La Cellule, xi, 27–52, pl. i, '95–'96.

Material of the *Liriodendron* collected on Oct. 20, 1897, was upon examination found to have an abundance of starch in the cells of the cortex but none in the cells of the medullary sheath and but few grains in the cells of the wood parenchyma and medullary rays. The cells immediately below the growing point of the stem contained no starch at this time. At this time practically all the leaves had fallen and the amount of starch now present represents the maximum amount. An examination of twigs from the same tree during the months of November and December showed a gradual increase in the amount of the starch in the medullary sheath but a marked decrease in the amount present in the cortex. During all this time there was some starch in the wood parenchyma and even more in the medullary rays. There was at this time a considerable amount of starch in the pitted cells that form plates across the pith in this species; but none was found in the other cells of the pith, which latter had no protoplasmic contents. The cells below the growing point up to this time contain no starch and in fact none is found there till about the first of March. The January collections show a gradual reduction of the amount of starch in the cells of the wood parenchyma and the medullary rays and medullary sheath. We reach finally a period at the end of February when starch begins to appear again in the cortex but more especially in the cells which lie beneath the growing point, i. e. in that dome-shaped group of cells that is called the pith cap. The cells of this cap are much the same in histological structure as those of the medullary sheath. The last collections, those of March, show still more starch in this region above the pith cap and less in the medullary sheath with quite a large quantity in the cortex.

The same statements will hold good for *Pyrus malus* except that some starch was found in the medullary sheath, medullary rays and the wood parenchyma on Oct. 20, 1897. In this species some starch could be found in the cortex all winter but in other respects the starch distribution was much the same as in *Liriodendron*.

The facts just stated for these two species will hold good, with slight individual variations, for the other species examined. In trees growing under our conditions I have found no such marked reduction in the total amount of the starch in the twigs as was reported by Fischer, '88 and '90. The only alterations I find are simply a general movement of the starch from the more peripheral and exposed regions to the more deep-seated and protected regions of the stem during the winter and a return again in the spring to the cortex and the regions of growth.

Further studies, now in hand, will trace the condition of the

starch and other cell contents throughout the entire year. Two associated questions are being examined in connection with the foregoing, (1) the determination of the behavior of the leucoplastids in the starch-bearing cells in the stems of our deciduous trees during this period of dormancy, and (2) the part which the intercommunicating threads of protoplasm play in the translocation of starch.

Questions in regard to the partial transfer of protoplasm itself inward from the cortex and back again at certain periods are being incidentally examined.

The slight changes in the reserve food material during the period of dormancy have an important bearing on the interesting speculation as to the relation existing between plants of temperate climates and their possible ancestors which thrived under the conditions of a warmer and more equable climate. The relations of all this to the question of biological protections are sufficiently obvious.

Botanical Laboratory of Harvard University, May 14, 1898.

Bibliography.

[Below are given those papers that are referred to in this article.]

Baranetzky, J., '84: (A note on starch translocation) Bot. Centralb., xviii, 157–158.

Famintzin, A. u. Borodin, J., '67: Ueber transitorische Stärkebildung bei der Birke. Bot. Zeit., xxv, 385–387.

Fischer, A., '88: Glycose als Reservestoff der Laubholzer. Bot. Zeit., xlvi, 405–417.

Fischer, A., '90: Beitrage zur Physiologie der Holzgewächse Jahrb. f. wiss. Bot. xxii, 73–160.

Grebnitzky, A., '84: Ueber die jährliche Periode der Stärkespeicherung in den Zweigen unserer Bäume. Bot. Centralbl. xviii, 157.

Gris, A., '66: Réchérches pour servir a l'histoire physiologique des arbres. Comptes Rendus, lxii, 438–443.

Gris, A., '66*a*: Nouvelles réchérches pour servir a l'histoire physiologique des arbres. Comptes Rendus, lxii, 603–607.

Hartig, T., '58: Ueber die Bewegung des Saftes in den Holzpflanzen. Bot. Zeit., xvi, 329–335, 337–342.

Müller-Thurgau, H, '82: Ueber Zuckeranhäufung in Pflanzentheilen in Folge niederer Temperature. Ein Beitrag zur Kentniss des Stoffwechsels der Pflanzen. Landw. Jahrb., xi, 751–828.

Müller-Thurgau, H., '85: Beitrag zur Erklärung der Ruheperioden der Pflanzen. Landw. Jahrb., xiv, 851–907.

Russow, F., '84: Schwinden und Wiederauftreten der Stärke in der Rinde der einheimischen Holzewächse. Sitzb. d. Naturf. Gesell. b. d. Univ. Dorpat., vi, 492–494.

Schröder, J., '69: Beitrag zur Kentniss der Frühjahrsperiode des Ahorns (Acer platanoides). Jahrb. f. wiss. Bot. vii, 261–343, pl. 13–20.

Art. VIII.—*Metamorphism of Rocks and Rock Flowage;* by C. R. Van Hise.

[Condensed by the author from the Bull. Geol. Soc. Am., vol. ix, 1898, pp. 269–328.]

The paper of which this is condensed is adapted from a partly written treatise on the subject of metamorphism and the metamorphic rocks.

In the article some of the more important physical and chemical principles which concern the alterations of rocks are summarized, and these principles are applied to the alterations which occur in connection with dynamic action.

Summary of Physico-Chemical Principles.

The agents through which the alterations of rocks take place are water solutions and mineralizers. In the present discussion mineralizers will not be considered.

Below the level of the free surface of underground water the rocks are practically saturated; above that level the rocks are not ordinarily saturated, but upon the average contain a considerable amount of water held by adhesion between the liquid and the solid mineral particles. Both below and above the free surface, water is the all-prevailing agent through which the chief alterations of rocks are accomplished.

The forces of metamorphism are (1) dynamic action, (2) heat, and (3) chemical action. In all of the various kinds of metamorphism ordinarily recognized in classification, such as hydro-metamorphism, static metamorphism, pressure metamorphism, dynamic metamorphism, regional metamorphism, contact metamorphism, and thermo-metamorphism, all of the forces above mentioned are required, and also the agent, water. There is no metamorphism of a rock without the presence of water, and hence all metamorphism is partly hydro-metamorphism; there is no metamorphism of a rock without motion, either molecular or mass, and hence all metamorphism in an exact sense is partly dynamic; there is no metamorphism of a rock without the presence of heat, and hence all metamorphism is partly thermo-metamorphism; there is no metamorphism of a rock in which chemical action does not enter, and hence all metamorphism is partly chemical metamorphism. When it is realized that in all the varieties of metamorphism mentioned, chemical action, heat, and dynamic action enter as factors, only in different degrees, and when it is remembered that water is the universal agent which is present and active wherever metamorphism occurs, it is self-evident that the classifications of metamorphism ordinarily given are not satisfactory.

A critical examination of the classifications of metamorphism shows that the kinds of metamorphism recognized in the text-books are based upon the idea that the particular force or agent mentioned is dominant in the production of the particular metamorphism. However, the classifications involve different factors, not belonging to the same category. For instance, thermo-metamorphism refers to heat; contact metamorphism refers to the contiguity of an igneous rock; hydro-metamorphism refers to the presence of water. As a matter of fact, all of the different kinds of metamorphism are related in the most intricate manner, and certain kinds of metamorphism which have been called thermo-metamorphism might just as well be called hydro-metamorphism.

Underground Flowage of Water.

Underground water, the agent of metamorphism, needs to be considered from two points of view—(1) its movement and (2) its work.

(1) *Movement of underground water.*—The movements of underground waters are dependent upon (*a*) head, (*b*) the underground openings, and (*c*) viscosity.

(*a*) The flowage of underground water is caused by head. Head is due chiefly to difference in the level at which the water enters and issues from its underground course. It may, however, be partly due to difference in temperature in the descending and ascending columns.

(*b*) Openings in rocks may be divided into (1) openings which are larger than those of capillary size, (2) capillary openings, and (3) subcapillary openings.

To movements of water in openings larger than those of capillary size the ordinary laws of hydrostatics apply. To movements of water in capillary openings the laws of capillary flow apply. By subcapillary openings are meant those in which the attraction of the solid molecules extends from wall to wall, and in these flowage is either exceedingly slow or does not occur.

(*c*) The elements entering into viscosity are the concentration of the solutions and the temperature. The viscosity of water decreases very rapidly with rise of temperature, and hence the high temperature in the lower part of the zone of fracture is very favorable to flowage.

(2) *Work of underground water.*—The potency of water as an agent through which metamorphism may take place is due, according to the modern ideas of physical chemistry, to its capacity to separate substances which it holds in solution into their free ions. In this power of ionization it exceeds all other solvents.

In order that crystals shall grow during the metamorphism of rocks, it is necessary that the solutions shall be saturated or supersaturated at the immediate place of crystal growth. As underground there is always a superabundance of material present as compared with the amount of water, we may suppose that at a moderate depth below the surface, and especially in the smaller spaces, where movement is slow, the solutions are often saturated. In the laboratory it is a well known fact that under conditions of saturation, with a superabundance of material, the larger crystals grow at the expense of the smaller ones, and that this process goes on more rapidly in proportion as the temperature is high and the pressure is great. In rocks this principle explains the growth of large mineral particles at the expense of smaller ones.

Forces of Metamorphism.

The work of underground water is accomplished by the forces of mechanical action, heat, and chemical action.

Dynamic action.—No changes in rocks take place without movements of materials, small or great, for short or long distances. Wherever there is rearrangement of the elements, there must be movements; even in the case of a mineral passing from one form to an allotropic form, there is movement of the molecules.

Mechanical action assists water in its work by producing in substances a state of strain which may pass to the stage of pulverization. Moreover, dynamic action produces effects through chemical forces and heat and by the agency of water. The more important laws of the relations between pressure and chemical action are as follows: "If we compress a chemical system at constant temperature, there follows a displacement of the equilibrium in that direction which is associated with a diminution of volume. . . . Thus the solubility of a salt in water, e. g., will increase with the pressure, provided that the dissolving is associated with a contraction of the solution plus the salt, and, conversely, the solubility will decrease if the separation of the salt (from the solution) is associated with a diminution of the volume of the system." The first of these cases is that applicable to underground water solutions. "Moreover, those chemical forces are strengthened by compression which condition a diminution of volume; and those chemical forces are weakened by compression which condition an increase in volume."

Heat.—All metamorphism takes place through the assistance of heat. Nowhere upon the surface of the earth, nor within the earth, is the temperature absolute zero. The activity of the molecules, or their kinetic energy, increases in proportion

to the heat, and the chemical activity may be enormously increased by a slight increase in kinetic energy of the molecules. The temperature is therefore a most important factor in the rapidity of the changes of all kinds.

For instance, the activity of water is greatly increased by rise of temperature. A slight rise of temperature may increase its rate of solution several fold, or out of all proportion to the absolute change in temperature. At temperatures above 100° C., and especially above 180° C., the activity of water may increase to an amazing degree.

Heat for the alteration of rocks is derived (1) from deep within the earth by conduction, or by convection through water or magma, (2) from dynamic action, (3) from chemical action, and (4) from the sun.

Chemical action.—No change takes place without chemical action. By chemical action is meant the taking of material into solution, the deposition of material from solution, the interchange between materials in solutions, the interchange between materials in solutions and adjacent solids, and, finally, possibly the interchange of the adjacent solid particles. I say possibly, for such an apparent interchange is probably accomplished through the medium of a separating film of water, in which case the apparently simple reaction is really accomplished by transfers between the solutions and solids. In all these interchanges, including those of simple solution and deposition, according to the modern ideas of physical chemistry, the salts are separated into their ions, and it is by the migration of these free ions that the interchanges are accomplished.

Relations of chemical action, heat, and pressure.—The more important laws expressing the relation of chemical reactions and heat are as follows: "If we heat a chemical system, at constant volume, then there occurs a displacement of the state of equilibrium, and in that direction toward which the reaction advances with absorption of heat." "Those chemical forces which condition a development of heat, will always be weakened by an increase of temperature; and conversely, those which condition an absorption of heat will be strengthened by such an increase in temperature; and it is this fact which, primarily, gives the preceding proposition its universal validity." "If we heat the system therefore, the reaction which takes place will be accompanied by absorption of heat; if we cool the system, the corresponding reaction will develop heat." "On the whole, the preponderating chemical reactions at lower temperatures are the combinings (associations) which take place with the development of heat: while the reactions preponderating at higher temperatures are the cleavings (dissociations) which take place with the absorption of heat." This ast is van't Hoff's law.

"In general, in comparing substances which are chemically analogous, and soluble with difficulty, the heat of precipitation (= the negative value of the heat of solution) is greater the more insoluble the substance is."

Finally, the relations between heat, pressure, and chemical action in a solution may be generally expressed as follows: "Every change of one of the factors of an equilibrium occasions a rearrangement of the system in such a direction that the factor in question experiences a change in a sense which is contrasted with the original change."

Application of Physico-Chemical Principles to the Earth's Crust.

It is evident from the foregoing principles that within the superficial zone of rocks in which reactions take place directly under our observation, and within the deeper-seated zone in which reactions have taken place and later have been brought within our observation, there may be opposing tendencies. The changing factors in these two physico-chemical zones are temperature and pressure and consequently chemical action. Both of these increase with depth.

Upper Physico-chemical Zone.

The chemical reactions which occur within the upper zone of observation of the earth are at the lower temperatures referred to in van't Hoff's law. Hence near the surface the reactions usually, if not always, take place with the liberation of heat, according to the first part of van't Hoff's law. The pressure near the surface is small, and therefore the law of chemical reactions with the liberation of heat in the outer zone is the dominating factor.

Hence an alteration may take place which works with or against pressure. In the first case, both the chemical reaction and the compression in volume result in the liberation of heat; in the second case, the heat liberated is that developed by the chemical reaction minus that absorbed as a result of the work done in expanding the volume.

The upper physico-chemical zone is divisible into two parts, the reactions within which strongly contrast: (1) an upper belt, mainly above the level of underground water, which is generally known as the belt of weathering, where disintegration, decomposition, and solution are the rule, and (2) a lower belt of greater thickness, in which cementation of openings is the rule, and therefore a belt in which induration is one of the most characteristic features.

Lower Physico-chemical Zone.

From the surface to considerable depth below the surface, the temperature ever becomes higher, and consequently the temperature may become so high that the tendency for reactions to take place which result in the development of heat is less dominant. However, at moderate depth, under ordinary conditions, say at 9,000 meters, the temperature is not very high, probably in the neighborhood of 300° C. Thus the tendencies for reactions to take place under the first part of van't Hoff's law, rather than the second part, would generally still control for a very considerable depth if it were not for the enormous pressure. In the lower zone this ordinarily becomes the dominating factor, especially in places of mass dynamic action, and reactions take place which result in the production of less volume, the chemical forces which condition a diminution of volume being very active, and the chemical forces which condition an increase of volume being very weak or even overcome.

Relations of the Two Physico-chemical Zones.

In so far as energy is concerned, there are four cases: The chemical reaction may (1) release energy, and result in the liberation of heat; (2) may consume energy, and result in absorption of heat. The change of volume may be (3) by compression, and result in the liberation of heat, or (4) by expansion, and result in the absorption of heat. (1) and (3) will be called plus, and when they are combined the heat liberated is equal to their sum; (2) and (4) will be called minus, and when they are combined the heat absorbed is equal to their sum. When (1) and (4) or (2) and (3) are combined, heat may be liberated or absorbed, depending upon the relative values of the energy of the chemical reaction and that of the change of volume.

As a case in which the reactions as to temperature and pressure are each in opposite senses in the upper and lower physico-chemical zones may be mentioned hydration and dehydration. The first process occurs in the upper zone, and represents an association which takes place with the great liberation of heat, while the second process occurs in the lower zone, especially in connection with mass dynamic action, and represents a dissociation which takes place with important absorption of heat. The first process results in very considerable expansion of volume; the second process results in equivalent contraction of volume.

A second important reaction separating the outer crust of the earth into two physico-chemical zones is the mutual replace-

ment of oxygen and sulphur. In the upper zone oxygen replaces sulphur, and at the same time may largely oxidize that element. This results in great liberation of heat, and in some cases also in expansion of the volume of the solid compound, as in the case of the production of limonite. Oxidation may take place without replacing another element, as when iron protoxide is changed into sesquioxide with expansion of volume and liberation of heat. In the lower zone sulphur may replace oxygen with condensation and with great absorption of heat.

Another set of reactions of the most fundamental importance and widespread character, in which the first part of van't Hoff's law of chemical reactions and the law of pressure stand opposed to each other, and which occur in an opposite sense of the two physico-chemical zones, is the mutual replacement of carbon dioxide and silicon dioxide. Near the surface carbon dioxide replaces silicon dioxide, with great development of heat, and expansion, provided the freed silica separates as quartz. The general fact of the carbonation of the silicates under these conditions the world over is well known.

In the lower physico-chemical zone, and especially under mass dynamic conditions, silica replaces carbon dioxide upon the most extensive scale with great absorption of heat and with condensation, comparing the combined volumes of the original carbonate and silica with that of the resultant silicate. As illustrations of this may be mentioned the formation of wollastonite from pure limestone, of tremolite from dolomitic limestone, and of actinolite and grünerite from ankerite or from siderite. In the impure limestones under deep-seated conditions, where numerous bases are present, various complicated silicates form, such as other pyroxenes and amphiboles, and tourmaline, chondrodite, et cetera. As illustrating the very considerable condensation in silication wollastonite may be taken, the volume of which is 31·5 per cent less than that of the combined volumes of the calcite and silica from which it may be produced.

As a corollary to the foregoing pages is the conclusion that in the upper zone, where pressure is relatively unimportant, upon the average, alterations result in the expansion of the volume of the rocks; and in the deeper-seated zone, where pressure is important or dominant, upon the average, the alterations result in the contraction of the volume of the rocks. It follows as a further conclusion from this that the tendency of the alterations in the first zone is, upon the average, to produce minerals of lower specific gravity than the original minerals, while in the deeper-seated zone the tendency upon the average is to produce minerals of higher specific gravity.

Metamorphism from the Dynamic Point of View.

Dynamic action is of two kinds—molecular dynamic action and mass dynamic action. By molecular dynamic action is meant interchange between the molecules. Metamorphism by such interchange has generally been called static metamorphism. Molecular dynamic action is always accompanied in some degree by mass dynamic action. By mass dynamic action is meant deformation of the body of the rocks. To alterations in connection with such deformation the term dynamic metamorphism is usually restricted. Mass dynamic action is always accompanied by molecular dynamic action. It is recognized that there are all graduations between molecular dynamic action and mass dynamic action. However, in many regions the phenomena are produced mainly in connection with one or the other.

Molecular Dynamic Action.

Molecular dynamic action involves various degrees of movements.

(1) Presumably the lesser movements are the cases of change in crystalline form and of strain within the elastic limit. In the change of a substance from one crystalline form to another —as, for instance, of aragonite to calcite—the movement of the molecules may not involve more than a redistribution or re-arrangement of those which are adjacent. In the case of substances strained within the elastic limit the molecules are simply pressed slightly closer together or pulled slightly farther apart, and yet these very slight adjustments may have a most profound effect upon the physical properties of the materials.

(2) In a second class of movements there is a rearrangement of the chemical elements by which new compounds are produced from old compounds. Material may be added to or subtracted from a given mineral or from glass, or either minerals or glass may be altered into two or more other minerals, with the simultaneous addition or subtraction of material. The added material in any case may come from some other particle not far distant. The material subtracted in any given case may be added to another particle at a greater or less distance.

In the majority of changes by molecular dynamic action, under both (1) and (2), which come within our observation, the chemical reactions usually result in a liberation of heat or running down of energy, under the first part of van't Hoff's law. This may be illustrated by hydration, which is, perhaps, the most characteristic change of molecular action, such minerals as chlorite, kaolinite, zeolites and epidote forming abundantly.

The reverse chemical action, that taking place with the absorption of heat, occurs at great depth under mass static conditions.

The foregoing principles of alterations under molecular dynamic conditions are applied to the devitrification of glass and to the recrystallization of minerals.

Some of the more distinctive features of molecular dynamic action are the growth of large individuals and preservation or emphasis of previous textures and structures.

Mass Dynamic Action and Accompanying Molecular Dynamic Action.

It has already been stated that in connection with mass dynamic action, molecular dynamic action invariably occurs. The kind and amount of resultant metamorphism varies greatly, depending upon depth, upon the particular kind of deformation, and upon other factors. It has been shown in another place that, depending upon depth, there are three important zones of deformation of which we have definite knowledge: (1) An upper zone of fracture, (2) an intermediate zone of fracture and flowage, and (3) a lower zone of flowage.

Zone of fracture.—In the zone of fracture deformation is accomplished by considerable movements along surfaces or zones, with little or no movements between these planes or zones. Such fractures are faults, joints, fissility, bedding partings, and the spaces of autoclastic rocks. The rocks are broken by these fractures into great regular masses, blocks, or leaves or into the irregular fragments of a dynamic breccia. Into these openings water readily enters to assist in the modifications. The movements between the individual mineral particles are largely confined to thin layers along the walls of the openings, and the conditions may be here those of important interior deformation, but for the masses of rock between the fractures the conditions are those of molecular dynamic action already described, and the changes are correspondingly slow. The rapid changes are confined to the material adjacent to the openings. From the places of entrance waters may permeate the adjacent rocks to a greater or less distance, and consequently molecular dynamic metamorphism may occur to a much greater extent than it would be were it not for the fracturing. The alterations of the thin layers of material adjacent to the openings are by interior movements, which are in all respects like those of kneading described under the zone of flowage.

It follows from the foregoing that the deformation accomplished by widely spaced fractures does not result in the obliteration of the original textures and structures, except adjacent to the fractures. The rocks are merely jointed,

sliced, piled up, or brecciated, and in each block or slice the alterations are metasomatic, or those of molecular dynamic action.

Zone of combined fracture and flowage.—In the middle zone of combined fracture and flowage the alterations may combine those of fracture and of flowage.

Zone of flowage.—At the outset it may be said that the process of rock flowage is very different from the flowage of a liquid.

It has been explained in another place that in the deep-seated zone of rock flowage the process of deformation is similar to that of mashing or kneading. There every particle, small or great, takes part in the deformation.

As soon as interior movements begin, the destruction of the original textures and structures begins and goes on very rapidly, so that with comparatively little motion the original textures may be wholly destroyed. For instance, such rocks as quartzose sandstones, which retain their textures for indefinite periods if there be no mass action, even when buried under thousands of feet of other rocks, when deformed by mashing rapidly lose all clastic textures. In the same way the textures which are characteristic of igneous rocks rapidly disappear by mashing. In the place of the original textures, whether those of sedimentary or igneous rocks, there appear peculiar textures and structures referred to subsequently as characteristic of mass dynamic metamorphism.

During the interior mass movements of rocks water makes its way between the particles much more readily than under conditions of quiescence. This follows partly from the movements and partly from the heat developed by the movements. The increased temperature results in decreasing the viscosity of the water, and it has been seen that low viscosity is of great importance in the penetration of water through minute spaces.

Consequent upon interior mass movements two kinds of deformation occur, granulation and recrystallization. Between the two are all gradations. Where the movements result in granulation this exposes large surfaces to the action of the contained water. The dissolving power of water when not nearly saturated is almost directly in proportion to the area upon which it can act. One perhaps might expect that the more profound the kneading the finer would be the granulation of the altered rock, but this is not the case. Many of the most profoundly altered rocks, instead of being extremely fine grained, are somewhat coarsely crystalline.

It is generally agreed that the crystalline schists of this character have been recrystallized throughout, and therefore strongly contrast with those rocks which have been granu-

lated. However, the granulated and recrystallized rocks are not separated sharply from each other, but, on the contrary, there is every gradation between the two. If in the altered sedimentary rocks one passes from a place of granulation to one of recrystallization, he finds that recrystallization of the matrix begins while granulation of the larger particles is still going on. Whether granulation or recrystallization is the dominant process in a given place in the zone of flowage depends upon many factors. Some of these factors are the character of the material, water content, temperature, pressure, and rapidity of deformation. Refractory minerals are favorable to granulation; mobile minerals are favorable to recrystallization. Absence of water is favorable to granulation; presence of water is favorable to recrystallization. Low temperature is favorable to granulation; high temperature is favorable to recrystallization. The less the pressure the more likely is the deformation to be accomplished by granulation. The greater the pressure the more likely is the deformation to be accomplished by recrystallization. To a certain point, the more rapid the deformation the more likely is the adjustment to be by granulation. The slower the deformation the more likely is the readjustment to be by recrystallization.

Some of the more characteristic features of the crystalline schists are their evenness of grain, and the similar crystallographic orientation of the authigenic particles of some of the minerals.

In the recrystallization of rocks in the deep-seated zone adjustment may not lag far behind the disturbing forces. However, in most cases there is apparently some lag. In the most regularly laminated of the crystalline schists a close examination usually shows a slightly undulatory extinction, and therefore a state of strain in the minerals, showing that recrystallization has not exactly kept pace with deformation, or else that they have been somewhat deformed nearer the surface since recrystallization.

It is concluded that the development of the crystalline schists is to be explained as a process of chemical reaction induced by mechanical action, resulting in the constant solution and deposition of the material so as to accommodate it to the changing form of the mass.

Comparative energy required for deformation in the three zones, of fracture, fracture and flowage, and flowage.—The energy required for deformation in the three zones of fracture, fracture and flowage, and flowage, is discussed, and the conclusion is reached that the amount of work done, in order to produce the same mass deformation of the rocks, increases down

to the zone of recrystallization and then decreases for a certain depth. No conjecture is made as to how far down this decrease continues but it is believed to be probable that the decrease continues at least as deep as the zone in which the schists formed by recrystallization develop.

Meaning of Rock Flowage.

I have previously maintained that the rocks within the scope of our observation which have been deformed at considerable depths were deformed by rock flowage. However, I made no attempt to explain what actually occurred during the process.

I shall take as a typical example of rocks which have been deformed in the zone of flow those laminated crystalline schists the mineral particles of which now show slight or no strain; for it is evident that these are the rocks which have nearly perfectly accommodated themselves to the deformation through which they have passed. The accommodation, as already explained, is accomplished by continuous solution and deposition, or by continuous recrystallization. While the adjustment during deformation at any moment was nearly as complete as though the rock were a magma, and while it nowhere shows more than a microscopic space, it is evident that the flowage is wholly different from that of a liquid. At no time was the rock a liquid. On the contrary, it was at all times almost wholly a crystalline solid. At no time was more than an almost inapplicable fraction of it in a liquid form—that is, dissolved in water—yet at all times it was adjusting itself by means of this small percentage of water contained in the capillary and subcapillary spaces, this being the medium of solution and recrystallization. In order that such a continuous process shall be adequate to explain rock flowage, it is necessary only that it shall be sufficiently rapid to keep pace with the deformation. One's first thought is probably that it is not possible that the process can be sufficiently rapid to account for the phenomena. However, the experiments of Barus upon the solution of glass give us a basis upon which we can make a quantitative calculation.

Barus has shown that a temperature of 180° C. is critical so far as the solution of glass by water is concerned. At temperatures lower than this the rate of solution by water is very slow. However, at temperatures of 185° C. and above, solution and crystallization of the silicates of glass go on with astonishing rapidity. In Barus' experiment water dissolved a sufficient amount of glass and deposited the material as crystallized minerals to cause an apparent contraction of volume of the water amounting to 13 per cent of the water present in the capillary tubes in 42 minutes and 18 per cent in an hour. This shows that solution continued during the later stages of

the experiment at about the same speed as during its earlier stages, for 13 : 42 about as 18 : 60.

During the experiment, unless hydrous minerals were produced, the water remained a constant quantity, and continued work. This could have been continued so long as the temperature and pressure were sufficient and glass was available for crystallization through solution, as a result of which the material is condensed. If no hydrated minerals are formed, there is no reason why a small amount of water cannot continue the process indefinitely.

If in this experiment we suppose the condensation of recrystallization to be 10 per cent, the amount of condensation in diabase in passing from the glassy to the crystalline condition, as shown by Barus, this would mean (neglecting the condensation of the water) that in one hour, in order to have given an apparent volume contraction of 18 per cent, the water had dissolved 1·8 times its own volume of the glass, and deposited crystallized material with 10 per cent less volume. Therefore, for the water to dissolve a volume of glass equal to that of the water and deposit it in a crystallized form would require 33⅓ minutes, or approximately one-half hour.

During the process of deformation of the rocks the material, if not dissolved, may be strained even to the point of granulation by the mechanical processes ; also so far as strain occurs, or the particles are small, the minerals are in a state in which solution is easier than for unstrained or larger mineral particles. However, it is probable that the solution of such mineral particles and the deposition of the material in an unstrained crystallized condition is considerably slower than that of amorphous glass, for it cannot be supposed that the same amount of energy is potentialized in the mineral particles as in the glass. But the further the strain goes before fracture the more energy is potentialized, or if fractures occur smaller particles are produced. Moreover, the contained water is in small capillary or subcapillary spaces, and therefore a given volume is acting upon a much larger surface than in the capillary tubes used by Barus in his experiments. In so far as granulation occurs, the surface for action is still further increased. All these conditions are favorable to solution and redeposition ; therefore the greater the straining and resultant granulation, the more rapid the process of recrystallization ; hence in the deep-seated zone mechanical disintegration never gets far in advance of solution and redeposition.

If it be supposed in the capillary and subcapillary spaces within the rocks that the speed of solution of minerals is ·1 of that of glass, water would dissolve its own volume of minerals and redeposit the material in about five hours. If the deep-seated rocks be supposed to contain 2 per cent of water by

volume—that is, less than 1 per cent by weight—the entire mass of rocks might be recrystallized in about 250 hours, or little more than 10 days. The percentage of water premised is known to be lower than the amount ordinarily found in the crystalline schists, and the rate hypothesized seems reasonable; but if this speed be decreased to ·1 of that suggested or ·01 of that of glass, still the entire mass of the rocks might be dissolved and reposited in about 100 days. Make the rate of ·1 of this or ·001 of that glass, and still recrystallization might be complete in about 1,000 days, or three years. It it be supposed that a mountain-making period occupied 150,000 years, and this is probably less rather than more than the time required for most mountain-making movements, during this period, at the slow rate suggested, the rocks could be recrystallized 50,000 times by 1 per cent of water, and this number certainly seems adequate to fulfill the requirement that at any given moment the crystalline rock shall exhibit but a slight strain effect.

Of course, it is not thought probable that any rock has completely recrystallized 50,000 times. Indeed, it is well known that many of the rocks in which recrystallization is complete, in so far as the finer particles are concerned, contain many larger particles which have not been completely recrystallized or even granulated.

If the case of a large grain of quartz or feldspar in a recrystallizing rock be taken, we may suppose the process to go on somewhat as follows: Because of the lack of homogeneity of the rock the stresses are irregularly distributed. At the most exposed places upon the mineral particles the conditions are favorable for solution, for the following reasons: the particles are there greatly strained, perhaps to the point of granulation, and, so far as strain exists or small granules are formed, these conditions are favorable to solution. At the places of great strain the material is therefore taken into solution and transported to the parts of the particles less strained. At such places the conditions are favorable to deposition, on account of the relatively large size of the residual original grains as compared with the granules. A mineral where least strained separates from the solution material like itself, attaching it to itself, in orientation with the core, in an unstrained or little strained condition. The process of growth is analogous to that of mineral growth by secondary enlargement. The entire process is similar in several respects to that of the continuous solution and deposition of calcium carbonate in the chemical laboratory when water is passed through a layer of this material under pressure. Where the pressure is greatest in the upper part, the grains are taken into solution. At the

place of escape, where the pressure is least, the material is deposited from solution, and the grains increase in size or grow.

During the deformation of the rocks this process of solution and deposition of a mineral particle is continuous. In this rearrangement it is not supposed that the identical molecules which are taken from the more severely stressed parts of a grain are necessarily deposited at the places of less stress upon the grain. Undoubtedly there is great interchange of material between the particles by means of the solutions. It is, however, thought probable that in many cases of deep-seated deformation, where the passage of solutions is difficult and slow, that much of the identical material which is taken from a grain at one place is added to it at another place.

When new individuals are produced in any way, as by granulation or by the deposition of new mineral particles, perhaps as different species from any originally in the rock, they are subject to the same laws as the original mineral particles. Many have a tendency to form with similar crystallographic orientation. However, it is only rarely that the orientation of the particles of a given mineral approximates exactness. One mineral—for instance, mica—may be well oriented, whereas such minerals as quartz or calcite may not be oriented.

In proportion as the minerals readily respond to the forces of recrystallization or are mobile, they do not gain or retain regularity of arrangement. After mass movement has ceased the temperature may be sufficiently high and the heat be held for a sufficient time, so that the solutions may completely recrystallize the minerals under mass static conditions, and therefore orientation may be lost. In proportion as minerals do not readily recrystallize or stubbornly resist the force of recrystallization, the minerals once oriented retain their regularity of arrangement.

It is concluded from the foregoing that rock flowage, as deep as observation extends, is plastic deformation through continuous solution and deposition, or, in other words, recrystallization. During the adjustment all or only a part of the material may have passed through this change. However, if a matrix, plastic by recrystallization, be filled with rigid granules which are not recrystallized, the whole mass may be deformed by true flowage of the matrix and by slipping or shearing readjustment of the granules. So far as the average mass deformation is concerned, the result is substantially the same as though each rigid granule had not acted as a unit. Indeed, the same average mass deformation may be accomplished wholly by granulation and welding, as in Adams' experiments; but it may, perhaps, be doubted whether this is ever strictly the case with rocks in nature, for some small amount of water is present, and probably, even in the case of

apparent perfect granulation, some degree of solution and recrystallization from solution has occurred. In the case of the imperfect crystalline schists, which are very widespread rocks, the adjustment to the new form is accomplished in part by the process of differential movement of rigid granules and in part by solution and redeposition. It is only in the case of the typical granulated rocks that we can suppose that the process of deformation is mainly accomplished by the movement of the solid particles over one another, and it is only in the perfect crystalline schists that we can suppose that the deformation is accomplished almost wholly by recrystallization.

Nothing is said by the foregoing conclusions as to the condition of the material below the zone of the crystalline schists or the meaning of the flowage of such material.

The conclusions of the foregoing pages show clearly the meaning of rock cleavage. I have already held that this structure is largely due to the similar crystallographic orientation of numerous mineral particles, and especially those which are authigenic, and therefore that rock cleavage is a capacity to part largely due to the actual cleavage of the similarly oriented mineral particles. As the cleavage of mineral particles has long been known to be a molecular structure, it follows that the cleavage of rocks is also largely a molecular structure. I have also explained that the similar crystallographic orientation is frequently, perhaps usually, accompanied by an arrangement of the mineral particles with their longer diameters in the same plane as the cleavage, and that this dimensional arrangement is a factor in rock cleavage, although one of probably less importance in most cases than that of the crystallographic orientation of the mineral particles.

Recrystallization and Aqueo-igneous Fusion.

It is apparent that the conclusions of the foregoing paper have an important bearing upon the hypothesis of aqueo-igneous fusion. It appears that if water is present when the material, as a result of the mechanical subdivision or for any other cause, reaches the very moderate temperature of 180° C., the adjustment is accomplished mainly by recrystallization, and that fusion is not necessary to account for the plasticity of the rocks.

So far as the typical crystalline schists themselves are concerned, it is certain that they are not the products of aqueo-igneous fusion. They have peculiar textures characteristic of themselves, which are wholly unlike textures of unmodified sedimentary rocks, and unlike those which are known invariably to appear in rocks which have crystallized from a magma, however the magma has been produced. Every magma crys-

tallizes according to the laws of magmas, and produces textures which are characteristic of such crystallization, and these are widely different from those of the crystalline schists.

It does not follow from the foregoing that the deeply buried rocks, including the crystalline schists themselves, may not become modified or even fused by contact with igneous intrusives.

Summary of Conclusions.

I here repeat some of the more fundamental principles stripped of qualifications:

(1) The chemical alterations which rocks undergo vary greatly under different conditions. The more important of these variable conditions are water content, temperature, pressure, and movement.

(2) The outer part of the earth, of which we have definite knowledge, may be divided into two physico-chemical zones. In the upper of these the reactions take place with the expansion of volume and with the liberation of heat, as end results. In the lower the reactions take place with the contraction of volume and with the absorption of heat, as end results. Some of the more important reactions in the upper zone are hydration, oxidation, and carbonation; some of the more important reactions in the lower zone are dehydration, sulphidation, and silication.

(3) The alterations under mass static conditions preserve previous textures and structures, but may go so far as to completely recrystallize the rocks. The alterations under mass dynamic conditions are different in the zone of fracture and the zone of flow. In the former the rocks are broken into fragments, and the alterations of the fragments are those of mass static conditions. In the zone of flow the alterations obliterate previous textures and structures and produce crystalline schists which have characteristic textures and structures.

(4) Rock flow is accomplished partly through mechanical strains, but mainly through continuous solution and deposition of the material of the rocks by the agency of the contained water. During the flow the rock is at all times almost wholly a solid, yet it responds like a plastic body to deformation without loss of its crystalline character, because of the continuous adaptation of the mineral particles, while in large parts retaining their integrity, to new forms by recrystallization.

(5) The energy required to produce a given mass deformation increases downward to the bottom of the belt of granulation. In the zone of flow by recrystallization the energy required to produce a given mass deformation is less, probably much less, than that in the lower part of the zone of fracture.

Art. IX.—*New Species of Ceratopsia;* by O. C. Marsh.

In the series of *Ceratopsia* remains which I secured in the West for the U. S. Geological Survey, and have since sent to Washington, several forms new to science are represented. One of the skulls, the type of *Triceratops elatus*, was sent in 1891, and with it two others belonging to *T. prorsus* and *T. sulcatus*, and these are now on exhibition in the National Museum. Among the *Ceratopsia* skulls, twelve in number, sent to Washington from New Haven during the present month, are two of much interest, both representing new forms.

Triceratops calicornis, sp. nov.

One of these, which may be called *Triceratops calicornis*, is of special importance, as not only the skull but the greater part of the skeleton of the animal is in good preservation, forming one of the most instructive specimens now known of this group of extinct Reptiles. The skull as a whole shows the well-marked features of the genus *Triceratops*. A specific character is seen in the nasal horn-core, which is in perfect preservation. It is directed well forward, and unlike any hitherto described is concave above, which fact has suggested the specific name. The upper or posterior surface of this horn-core somewhat resembles the bottom of a horse's hoof.

Some of the principal dimensions of this skull are as follows: Length from front of beak to back of parietal crest, about six feet, five inches; from front of beak to end of occipital condyle, three feet, five inches; distance from occipital condyle to back of parietal crest, four feet; from front of beak to point of nasal horn-core, twenty-three inches; height of post-frontal horn-core, twenty-nine and a half inches, and antero-posterior diameter of same horn-core at base, twelve inches.

Triceratops obtusus, sp. nov.

A second new species, which may be called *Triceratops obtusus*, is represented by a large skull belonging to the same genus. The nasal horn-core of this skull is very short and obtuse, and so well preserved that it indicates the normal form and size. The entire length of this horn-core is only one inch. Its summit is three and a half inches behind the premaxillary suture. The width of the nasals beneath the horn-core is five and a half inches. The length of the squamosal from the quadrate groove to the posterior end is about thirty-six inches, and its greatest width is nineteen inches.

These two skulls were both found by J. B. Hatcher, in the Ceratops beds of Converse County, Wyoming.

Yale Museum, New Haven, Conn., June 15, 1898.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Vapor Pressure of reciprocally soluble Liquids.*—It has been pointed out by Ostwald that the question whether two liquids are completely miscible with each other or only partially so miscible is in general a question of temperature. Since all vapors are completely miscible at all points above the critical temperature, evidently liquids must be completely miscible at this temperature. Below this temperature, however, a separation may occur. In 1891 Masson showed that there is a temperature at which this separation first occurs and which he called the "critical solution temperature." At this particular temperature the two saturated solutions formed by the liquids have the same composition and the same vapor pressure, and therefore give vapors having identical composition. At this point, consequently, the composition of the liquid must be the same as that of the vapor which is given off on boiling. Below this point, the composition of the distillate obtained from a mixture of two partially miscible liquids, may be considered, according to the author, as also that of a liquid mixture having, if homogeneous, the same composition as its vapor.—*Ann. Phys. Chem.*, II, lxiii, 336–341, December, 1897.

G. F. B.

2. *On Electric Energy by Atmospheric Action.*—An electric generator has been devised by Warren whose energy comes from direct atmospheric oxidation. Plates of a special porous compressed graphite are prepared, and about a fourth of each plate is made active by immersion in platinic oxalate, drying and igniting in an atmosphere of hydrogen. When placed in contact with a ferrous sulphate solution, oxidation of the iron by the oxygen of the air is effected through the agency of the platinum. The circular lead beam to which these plates are attached surrounds a porous diaphragm containing as the negative element a rod of amalgamated zinc, the carbon plates being arranged so as to allow the platinized portion to project above the solution, consisting of strongly acidified ferric sulphate. On completing the circuit a strong current is produced, which continues until the complete reduction of the ferric salt has taken place, when the action ceases. On withdrawing the zinc, the platinum surface condenses the atmospheric oxygen and so steadily re-oxidizes the ferrous salt, thus renewing the action.—*Chem. News*, lxxvi, 200, October, 1897.

G. F. B.

3. *On the Significance of Ionic Reactions in Electrochemistry.*—In a recent lecture on the bearing of the ionic hypothesis on analytical chemistry, Küster made some interesting experiments. The electric exchange $Cu^{++}+Fe=Cu+Fe^{++}$ was shown by placing pieces of iron near the top and of copper near the bottom, of a solution of sodium sulphate; on adding a few crystals of copper sulphate near the copper, a current flows at once from the copper to the

iron through the external circuit. If two iron plates be used in a solution of common salt, a little ferric chloride being placed near the lower one, the change produced illustrates the equation $Fe_2^{+++} + Fe = Fe_2^{++}$. In the case of the reversible reaction $Fe^{++} + I = Fe^{+++} + I^-$, the electrical exchanges were shown by means of two platinum electrodes standing in small crystallizing dishes placed within a larger dish, the latter being filled with a solution of potassium chloride. In one of the small dishes is contained some iodine and in the other ferrous chloride solution. Under these conditions the current in the external circuit flows from the iodine to the strong ferrous solution; but by increasing the concentration of the iodine ions or of the ferric ions, the reaction is reversed and with it the direction of the current. In a similar way the exchange $I^- + Br = Br^+ + I$ was shown. When electrodes of iron and platinum are immersed in a potassium chloride solution and a little iodine is added near the platinum, the current developed corresponds to the reaction $Fe + I_2 = Fe^{++} = I_2^-$. Again a saturated solution of hydrogen chloride in toluene does not conduct electricity even under a pressure of 72 volts; nor does such a solution act on calcium carbonate. But the addition of a little water enables it to accomplish both these results. A saturated solution (0·1 normal) of carbonic acid colors methyl orange less intensely red than a 0·01 normal solution of acetic acid, owing to their dissociation difference. By adding a trace of hydrogen sodium carbonate to the carbonic acid, the diminution of dissociation produced by increasing the concentration of one ion is shown by the disappearance of the red color. The same result follows the addition of sodium acetate to the acetic acid solution; though no change of color is produced when sodium chloride is added to a weak solution of hydrogen chloride colored by methyl orange. A similar phenomenon is the precipitation of lead chloride from its saturated solution by adding a solution of common salt. In the next place, if copper be present in the form of cation in a solution of copper suphate, or in that of a complex anion in Fehling's solution, this fact may be proved by passing a current through two U-tubes, in one of which is a solution of copper sulphate having one of sodium sulphate floating upon it, while in the other is the Fehling's solution and on it an alkaline solution of Rochelle salt. In the one tube the blue zone moves in the same direction as, and in the other in the opposite direction to, that of the current. The absence of cupric ions from Fehling's solution was further shown by means of a galvanic cell containing lead and copper immersed respectively in solutions of lead acetate and copper sulphate. Under these conditions, lead dissolves and copper is thrown down; but both the reaction and the direction of the current are reversed if an alkaline solution of Rochelle salt is added to the cupric sulphate solution.—*Zeitschr. Electrochem*, iv, 105–113, August, 1897. G. F. B.

4. *On the Photoelectric Properties of Certain Colored*

Salts.—Some years ago, Goldstein showed that many salts became colored under the influence of the kathode discharge, and that the salts so colored possessed the property of losing negative electrification readily when subjected to the influence of bright light. More recently, Giesel* has obtained a similar coloration by subjecting the salts to the action of sodium or potassium vapor. ELSTER and GEITEL have now shown that the salts colored by Giesel's method also show the photoelectric peculiarity observed in those colored by the kathode discharge. They have also noticed it in the case of some naturally colored specimens of rock salt. Hence it would appear probable that the coloration is due to a dilute solution of the metal in the solid salt, even though no indications of alkalinity in solutions of these colored salts were found by Abegg. There appears to be no evidence in support of Kreutz's view that the presence of iron salts is the cause of the coloration.—*Ann. Phys. Chem.*, II, lxii, 599–602, November, 1897.

G. F. B.

5. *On Combustion in Rarefied Air.*—Experiments have been made by BENEDICENTI upon the combustion taking place in a lamp fed with olive oil burned under various atmospheric pressure, with the object of elucidating the question of combustion at high altitudes. He finds that combustion is just as complete under 360^{mm} pressure, corresponding to an altitude of 6000 meters, as at ordinary pressures, the only difference being that the speed of combustion is less at the lower pressure. Moreover no appreciable increase occurs in the quantity of carbon monoxide produced as the pressure diminishes.—*Real. Accad. Linc.*, V, v, i, 40, 1896; *J. Chem. Soc.*, lxxiv, ii, 215, May, 1898. G. F. B.

6. *On Molecular Masses of Solid Substances.*—On comparing the densities of a number of solid organic substances, TRAUBE has been able to show that the volume of the group CH_2 is practically the same in solid as in liquid compounds. If we assume that this holds good also for the atomic volumes of the elements, it becomes possible to calculate the co-volumes for a number of solid substances. This done, the result appears that the co-volume forthe solid state appears to have about half the value which it possesses for liquids. But since a diminution of the co-volume on solidification can be due only to the association of molecules, it is assumed by the author that the co-volume in the solid state is in reality equal to that for the liquid state, Avogadro's law holding for the solid state. From this he is able to calculate the association factor for the compounds referred to, and finds that it is roughly equal to 2; all these compounds, therefore, in the solid form being bi-molecular. This conclusion appears to be confirmed by a comparison of a number of inactive racemic compounds, which are undoubtedly bi-molecular, with the corresponding active components. Since these latter are found to have the same co-volumes, they also must be bi-molecular. Applying to inorganic salts the same method, it follows that those

* See this Journal, IV, iv, 152, August, 1897.

which yield two ions are bi-molecular whereas those which yield three ions are monomolecular. Küster's experiments on naphthol and naphthalene are quoted by the author in support of his views, as also the fact that many solid compounds have vapor densities at low temperatures corresponding to a molecular mass double that which they possess at high temperatures.—*Ber. Berl. Chem. Ges.*, xxxi, 130–137, February, 1898. G. F. B.

7. *On the Liquefaction of Hydrogen.*— On the 10th of May, at the Royal Institution, DEWAR succeeded in effecting the complete liquefaction of hydrogen. As early as 1896, he had successfully produced a jet of hydrogen containing liquid, by means of which he was able to cool bodies below any temperature that could be produced by liquid air. It was resolved therefore to construct a larger apparatus of the same type, and the first experiments with it were made on the above date. In his paper read to the Royal Society on May 12th he says: "On May 10th, a start was made with hydrogen cooled to $-205°C$ and under a pressure of 180 atmospheres escaping continuously from the nozzle of a coil of pipe at the rate of about 10 to 15 cubic feet per minute in a vacuum vessel double silvered and of special construction, all surrounded with a space kept below $-200°C$. Liquid hydrogen commenced to drop from this vacuum vessel into another doubly isolated by being surrounded with a third vacuum vessel. In about five minutes, 20^{cc} of liquid hydrogen were collected, when the hydrogen jet froze up from the solidification of air in the pipes. The yield of liquid was about one per cent of the gas. The hydrogen in the liquid condition is clear and colorless, showing no absorption spectrum, and the meniscus is as well defined as in the case of liquid air. The liquid must have a relatively high refractive index and dispersion and the density must also be in excess of the theoretical density, viz., 0·18 to 0·12, which we deduce respectively from the atomic volume of organic compounds and the limiting density found by Amagat for hydrogen gas under infinite compression." . . . "Not having arrangements at hand to determine the boiling point, two experiments were made to prove the excessively low temperature of the boiling fluid. In the first place, when a long piece of glass tubing sealed at one end and open to the air at the other was cooled by immersing the closed end in the liquid hydrogen, the tube immediately filled where it was cooled with solid air. The second experiment was made with a tube containing helium." . . . "Having a specimen of helium which had been extracted from Bath gas sealed up in a bulb with a narrow tube attached, the latter was placed in liquid hydrogen, when a distinct liquid was seen to condense. From this result it would appear that there cannot be any great difference in the boiling points of helium and hydrogen." Although Olszewski has published an account of experiments in which hydrogen was obtained in a state of momentary or "dynamical" liquefaction, as a thin mist, in which state some of its constants were measured, Dewar's result, in which the hydrogen was produced as a "static"

liquid with a clearly defined meniscus, must be regarded as an achievement of a greatly higher order.—*Nature*, lviii, 55–57, May 18th, 1898; *Phil. Mag.*, V, xlv, 543, June, 1898. G. F. B.

8. *Some New Methods for the Measurement of Self-Inductance, Mutual Inductance and Capacity;* by H. A. ROWLAND and T. D. PENNIMAN. (From the Johns Hopkins University Circulars, No. 135, June, 1898.)—In the American Journal of Science, December, 1897, and in Phil. Mag., January, 1898, one of us published an account of a large number of new methods for the measurement and comparison of self-inductance, mutual inductance and capacity. Several of these methods have been tested in the Physical Laboratory of the University with great success, notably the methods for the *comparison* of the above quantities.

The methods involve the use of the electrodynamometer with an alternating current, and depend on one general principle—that is, that the deflection of the hanging coil of an electrodynamometer, if the hanging coil and the fixed coils of the electrodynamometer are originally at right angles, is proportional to the product of the currents in the hanging coil and the fixed coils, together with the cosine of the phase difference of the two currents. The dependence of the deflection on the cosine of the phase difference of the currents divides the methods into two general classes—methods in which there is a deflection, i. e., the cosine of the phase difference has a value; and methods of zero deflection, i. e., the cosine of the phase difference is equal to zero. The first class of methods gives the self-inductance or capacity in terms of resistance and b, i. e., 2π (the number of complete alternations per second of the current). These methods were very easy of application; the chief difficulty was the variation of b, as the current was generated in the power house of the University, where the engine was subject to great change of load. The presence of electric absorption also interfered with the accurate determination of the capacity of condensers.

The following method is an example of this class, and of the accuracy with which self-inductance can be determined even under these conditions. In this method the fixed coils of the electrodynamometer are in the main line or circuit, and the hanging coil is shunted off the main circuit around a small resistance, r. In the hanging-coil circuit is placed a non-inductive resistance, R, with a self-inductance, L, under which condition the hanging coil will have a certain deflection when the current is flowing. They, R and L, are now removed, and a non-inductive resistance, R', is substituted, which is adjusted to give the same deflection as when R and L were in circuit. Under these conditions,

$$b^2 L^2 = (R'-R)(R+r).$$

By this method and similar methods given in the article cited, values of self-inductance were determined that agreed among themselves to within about 1 part in 100, i. e., the determinations were made with about the same degree of accuracy as b could be

determined, on which quantity they directly depended. Taking into account absorption, capacity can be determined by the same method with about the same degree of accuracy. This method is easy to use, as it requires but one adjustment, R^1.

The methods for the comparison of the above quantities gave much more accurate results, as they are independent of the period of the current, the great cause of error in the measurement of the quantities. When care was taken to guard against all inductive and electrostatic action of the different parts of the apparatus on each other, the results derived by the different methods tried were remarkably good, notably the results obtained by the method for the comparison of two self-inductances. The connections for this method are made in this manner :

Let there be two coils of self-inductances, B_1 and B_2 placed together, and let the circuit pass through the coil B_2. From the main circuit, after it has passed through the coil B_2, the hanging coil of the electrodynamometer, having in circuit a self-inductance, L, and a resistance, R, is shunted around a small resistance, r. The coil B_1 is placed in circuit with the fixed coils of the electrodynamometer and a resistance, R^{11}.

The condition, then, for zero deflection when the current is flowing is

$$\frac{L}{B_1} = \frac{R+r}{R^{11}}$$

Using this method and taking B_1 as a standard equal to 1 Henry, several coils were compared with B_1, both singly and in series. To show with what accuracy self-inductances of different amounts can be compared, a few values are given for two periods. The coils being compared with B_1 as a standard.

	$n = 40$		$n = 133$		
Coils.	Results found by direct measurement.	Sums and differences of direct measurement.	Results found by direct measurem't.	Sums and differences of direct measurem't.	Sums and differences.
P_1	·5664	·5663	·5653	·5648	$(C+P_1)-C=P_1$
C	1·3050	1·3049	1·3034	1·3029	$(C+P_1)-P_1=C$
$C+P_1$	1·8713	1·8714	1·8682	1·8677	$C+P_1$

These are good cases of agreement, and show the accuracy of the method for the comparison of self-inductance of different amounts, when care is taken to eliminate heating and electrostatic action of the resistance and leads.

It will be noticed that the value of the self-inductance for the two periods is different; this was due to the electrostatic action of the turns of the coils on each other, and therefore could not be avoided.

When equal self-inductances are to be compared, the accuracy

depends only on the sensitiveness of the instrument to changes in $R+r$; and in the arrangement used in our experiments, the electrodynamometer was sensitive to changes of about 1 part in 10,000 in $R+r$. Therefore the construction of standard self-inductances that will agree with each other to within 1 part in 10,000 is feasible by this method.

9. *Some Notes on the Zeeman Effect;* by J. S. AMES, R. F. EARHART and H. M. REESE. (From the Johns Hopkins University Circulars, No. 135.)—In our investigation of the effect of the magnetic field on radiations in the ether, we have been led to study certain variations from the phenomena discovered by Zeeman, which seem to be worthy of note. Up to the present we have studied the effect of a magnetic field upon the spark-spectra of magnesium, iron, cadmium and zinc. The research is by no means complete, but having discovered several new effects we think it well to publish them at present, and to defer until later a full discussion of the phenomena.

Our apparatus has been the small concave grating of the Physical Laboratory, which has a radius of curvature of about eleven feet. The grating is ruled with 15,000 lines to the inch and is five inches in width. The magnetic field has been produced by an ordinary form of electro-magnet, but we have made no attempt to measure the intensity of the field, because our object has not been to establish numerial relations. The field, however, was strong enough to produce a separation in the case of iron of about a tenth of an Ångström unit, and the definition has been most satisfactory. The method of use was to introduce between the spark and the slit a Nicol's prism and quartz lens, and to photograph the resulting spectra along the middle of the photographic plate, then turning the Nicol's prism through 90°, and at the same time turning a shutter which is placed in front of the photographic plate, to expose the two edges of the plate to the new radiation coming through the Nicol's prism. By this method we secure on the same plate the components of the vibrations polarized along the lines of force and at right angles to them.

We have studied the effect of the magnetic field upon the iron spectrum from wave-length 3400 tenth meters to wave-length 4300, and in this region have noticed that all the lines, with certain exceptions to be noted, are influenced in the way discovered by Zeeman. In particular, when the radiation at right angles to the magnetic field is studied, each line in the spectrum is broken up into three, the central component being plane polarized, with its vibrations along the lines of force; the two side components being plane polarized at right angles to this, their vibrations being at right angles to the field of force.

We have observed, however, that three lines, of wave-length 3587·13, 3733·47 and 3865·67, are affected in the opposite way; that is, the line is a triplet when viewed at right angles to the magnetic field, but the central component is so polarized that its vibrations are at right angles to the field, and the two side components have their vibrations along the field.

Four lines, at 3746·06, 3767·34, 3850·12, 3888·67, have, so far as our indications go, no modification produced whatever. The lines at 3722·72 and 3872·64 are so modified as to be quadruplets, the central component which has its vibrations along the line of force being a close double. There are several other lines concerning which we have doubt, but most of the others examined are clearly modified in the way described by Zeeman. We have noted too that the separation of the side components of the triplets seems to be most irregular; lines whose wave-lengths differ by only a few Ångström units have displacements which differ by 20 per cent at least. In short, there seems to be no regularity in the separations produced. (Several of the above effects have been observed by other investigators.)

In studying the spectrum of cadmium we have observed that the lines at 4678·37, 4800·09, 5086·06, which belong to the "second subsidiary series," and the lines at 3467·76 and 3613·04 which belong to the "first subsidiary series," are all modified in the normal manner; that is to say, in the manner described by Zeeman, and by amounts which are no greater than for iron, but that there seems to be no regularity in the separations produced, either between the two series or between the lines of any one series.

We have been unable to extend our investigations into the extreme ultra violet owing to the fact that the Nicol's prism which we used in order to separate the components, absorbs the waves beyond 3400.

In the study of the spectra of zinc and of magnesium, we have not yet obtained results which are worthy of note.

10. *An Elementary Course of Physics.* Edited by Rev. J. C. P. Aldous, M.A. 862 pp. London and New York, 1898. (Britannia Series: The Macmillan Co.)—In this volume, the chapters devoted to Mechanics, Properties of Matter, Hydrostatics, and Heat have been prepared by the editor; those on Wave Motion, Sound, and Light, by W. D. Eggar; and those on Magnetism and Electricity by F. R. Barrell. The authors have certainly succeeded in giving a very satisfactory and attractive presentation of the subject of physics from the elementary and somewhat popular side. In many cases the subjects are introduced with a brief allusion to the historical development which is sure to make the matter more real to the student. Thus the opening paragraphs devoted to motion begin with the mention of Newton's observation of the falling apple; even a picture of the philosopher is added (perhaps unnecessarily, in this case). The principles are stated throughout in clear and simple language, and the frequent illustrations, verbal and pictorial, are much to be commended; the latter have been for the most part freshly prepared for this volume. Mathematical expressions are largely avoided, which fact, while limiting the usefulness of the book in certain obvious directions, makes it all the more readable for the class of students for whom it has been prepared.

11. *The Storage Battery.* A Practical Treatise on the Construction, Theory, and Use of Secondary Batteries; by AUGUSTUS TREADWELL, Jr., E.E. 257 pp. New York and London, 1898. (The Macmillan Co.)—The subject of storage batteries is one that has always been of great general interest, both from the theoretical and practical standpoints, ever since the earliest attempts in this direction. The present practical treatise is particularly acceptable because it is at once fresh and sufficiently thorough and scientific. Brief accounts are given of the many different forms of accumulators, and these are accompanied by numerous illustrations; those showing the discharge curves are especially valuable. The chemical theory, as now accepted, is explained, and an interesting chapter is devoted to a description of practical storage battery installations at many different points with data as to their practical working. The concluding chapter contains valuable suggestions as to the precautions to be observed in the use of accumulators and the conditions under which they give the best results.

II. GEOLOGY AND NATURAL HISTORY.

1. *Important Vertebrate Fossils for the National Museum.*—Prof. O. C. MARSH has recently transmitted from New Haven to the Director of the U. S. Geological Survey the fourth large instalment of Vertebrate Fossils secured in the West, in 1882–92, under his direction, as Paleontologist of the U. S. Geological Survey in charge of Vertebrate Paleontology. The collection is packed in one hundred (100) boxes, and weighs over thirteen (13) tons. In accordance with law, the material will be deposited in the National Museum. This collection includes twelve skulls and other remains of the gigantic *Ceratopsia* from the Cretaceous; various *Dinocerata* fossils from the Eocene; a series of rare specimens of *Brontotherium*, *Elotherium*, *Miohippus*, and other genera, from the Miocene; a very extensive collection of Rhinoceros and other mammals from the Pliocene; as well as various interesting fossils from more recent deposits.

The other important collections of Vertebrate Fossils secured by Prof. Marsh in the West for the Geological Survey, and previously transferred to the National Museum, may be briefly enumerated as follows:—

(1) Seventy-two (72) large boxes of Pliocene fossils, weighing about 7,500 lbs., were transferred December 31, 1886, and were stored in the Armory, February 8, 1887. The record of these boxes is on file in the office of the Geological Survey, and the Smithsonian numbers of the boxes are 6601–6672.

(2) Thirty-three (33) large boxes (weighing 6,960 lbs.) of rare Vertebrate Fossils, ready for exhibition, were transferred July 17, 1891, and were placed in a case specially prepared for them in the National Museum, before the opening of

the International Congress of Geologists held in Washington that year.

(3) Forty-three (43) large boxes (weighing 4,380 lbs.) of Pliocene Vertebrate Fossils were transferred April 17, 1896.

These various collections with other smaller consignments transferred to the National Museum (255 boxes in all, with a total weight of over 20 tons) were secured under the special direction of Prof. Marsh, as Paleontologist of the U. S. Geological Survey in charge of Vertebrate Paleontology, during 1882–92. The remaining collections thus made, and still at New Haven, will be sent to Washington as soon as their scientific investigation now in progress is completed.

2. *U. S. Geological Survey.*—A new publication of the U. S. Geological Survey has appeared as Folio 1 of the Topographic Atlas. It embraces ten maps selected to illustrate topographic forms described in an accompanying text, by Henry Gannett, and is intended for use in teaching Geography. The topographic types illustrated are:

A Region in Youth (Fargo, North Dakota), *Maturity* (Charleston, West Virginia), *Old Age* (Caldwell, Kansas), *Rejuvenated* (Palmyra, Virginia), also *A Young Volcanic Mountain* (Mount Shasta, California), *Moraines* (Eagle, Wisconsin), *Drumlins* (Sun Prairie, Wisconsin), *River Flood Plains* (Donaldsonville, Louisiana), *A Fiord Coast* (Boothbay, Maine), *A Barrier-Beach Coast* (Atlantic City, New Jersey). These features are illustrated by the sheets noted in parentheses.

3. *The Occurrence of Petroleum in Burma.* Volume xxvii, Part II, of the Memoirs of the Geological Survey of India, consists of a paper of 226 pages, with a large number of folded plates, by Dr. Fritz Noetling on the occurrence of petroleum in Burma, and its technical exploitation. This discusses the subject exhaustively, both from the scientific and technical side and further gives an interesting historical summary going back to legendary times. The chief locality is at Yenangyoung, on the left bank of the Irawadi, in the Magwe District, where the petroleum comes chiefly from certain argillaceous beds in the Upper Miocene. Another locality is near the village of Minbu, on the Irawadi, 423 miles above Ragoon; but this has not been exploited thus far to any considerable extent. Some other occurrences are also noted, as that at Yenangyat. It is stated that a peculiarity of the Burma petroleum consists in its large percentage of paraffine wax, which makes it a viscous oil. In consequence of this, at a temperature of 54° F., the petroleum which collects in some pools congeals and forms a greasy matter of the consistency of lard; thus during the winter months the pipe lines cool so much that the flow is seriously clogged. The petroleum contains about 50 per cent of illuminating oil with 40 per cent of lubricating oil and 10 per cent of paraffine wax. The oil from Yenangyat, however, is lighter and contains a larger quantity of illuminating oil than that of Yenangyoung. Previous to 1886 there was no

great variation in the production of oil, but in recent years the amount has run up very largely, and while it amounted to 34,000 barrels in 1886, it has become 257,000 in 1894, although it is remarked that this production is small in comparison to that of Baku or of the United States.

4. *A Text-book of Entomology;* by A. S. PACKARD; pp. xvii + 729, 8vo, 1 pl. and 654 figs. in text. New York, 1898 (The Macmillan Company; $4.50).—This, the latest of Prof. Packard's books on insects, occupies a comparatively new and increasingly important field among modern text-books of entomology. After a brief discussion of the relations of insects to other arthropods and the rest of the animal kingdom, the work is entirely devoted to anatomy, physiology, embryology and metamorphoses. Much the larger portion of the work is given up to the first of the three parts into which it is divided, that on external and internal anatomy, in which some account is given of the physiology of the more important organs, especially those involved in locomotion. The second part, on embryology, follows closely Korschelt and Heider's excellent text-book on the embryology of invertebrates, but the account of the maturation and fertilization of the egg is so brief and imperfect that it gives little idea of these processes. A more noteworthy defect is the apparent omission of any description of asexual reproduction, although the parthenogenetic eggs of *Cecidomyia* are described and figured. The final part, on metamorphoses, is naturally the most interesting part of the book and cannot fail to be of service to the general student of biology. The volume, which is well and profusely illustrated and admirably printed, will be appreciated by every one interested in entomology.

5. *Bibliotheca Zoologica II. Verzeichniss der Schriften über Zoologie welche in den periodischen Werken enthalten und vom Jahre 1861–1880 selbständig erschienen sind.* Bearbeitet von Dr. O. TASCHENBERG. Vierzehnte Lieferung. Signatur 521–560, pp. 4209–4528. Leipzig, 1898 (W. Engelmann).—The editor and publisher of this comprehensive work are to be congratulated upon its near approach to completion. The present Lieferung, No. 14, contains the closing part of the bibliography devoted to the Aves (pp. 4209–4364) and the opening part of the Mammalia (pp. 4365–4528).

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Seestudien:* Erläuterungen zur zweiten Lieferung des Atlas der österreichischen Alpenseen, von DR. EDUARD RICHTER. Geographische Abhandlungen herausgegeben von Prof. Dr. Albrecht Penck. Band vi, Heft 2, pp. 71. Vienna, 1897 (Ed. Hölzel).—The latest contribution to the admirable geographical memoirs edited by Prof. Penck is this paper on the Austrian Alpine Lakes, intended to serve as a text to the atlas which it accompanies. It gives an interesting account of the results of soundings made to

determine the exact form of the lakes, and further, a detailed statement of the observations of the temperature of the water through the different seasons of the year. The change of conditions from the time when the lakes were covered with ice to the warmer period of the summer, and again to their freezing in winter, has been traced out with great minuteness, and the results, while not in all respects novel, contain several points of interest. It is remarked, for example, that the warming of the surface water is accomplished exclusively by the direct radiation and is almost independent of the temperature of the air. The increase in surface temperature may amount to as much as six degrees in a day, though most of that is lost again during the night, particularly in the case of clear weather. At a depth of four meters the effect of the sun's rays may amount to as much as half a degree in a day, while at ten or twelve meters a warming of only one or two degrees in the course of the entire summer is noted; but great differences result according to the purity of the water. It was found, further, that the freezing over begins when the temperature has cooled down to + 1 or + 2, and a temperature of zero degrees before freezing was never observed. It is remarked that further investigations are needed to explain this anomaly. Attention is called in this connection to a paper by Arnet on the freezing of the lakes in Central Switzerland from 1890 to 1896, in which it is stated, in regard to Lake Luzerne, that during freezing and while ice covered the lake, no temperature below 1·25 C. was noted.

2. *Field Columbian Museum.*—The following are recent publications:

Publication 23, Anthropological Series, vol. ii, No. 2. A Bibliography of the Anthropology of Peru; by George A. Dorsey; pp. 57–206.

Publication 25, Botanical Series, vol. i, No. 4. Contribution III to the Coastal and Plain Flora of Yucatan; by Charles Frederick Millspaugh; pp. 345–410.

Publication 26, Zoological Series, vol. i, No. 9. List of a Collection of Shells from the Gulf of Aden, obtained by the Museum's East African Expedition; by Dr. W. H. Dall. D. G. Elliot, Curator of Department; pp. 187–189.

Publication 27, Zoological Series, vol. i, No. 10. Lists of Species of Mammals, principally Rodents, obtained by W. W. Price, Dr. S. E. Meek, G. K. Cherrie, and E. S. Thompson, in the States of Iowa, Wyoming, Montana, Idaho, Nevada, and California, with Descriptions of New Species; by D. G. Elliot; pp. 193–221.

The Pruning Book: A monograph of the Pruning and Draining of Plants as applied to American conditions; by L. H. Bailey; 537 pp. New York, 1898. (The Macmillan Company.)

The Social Mind and Education. By George Edgar Vincent. 155 pp. New York and London, 1897. (The Macmillan Co.)